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FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE

VOLUME I

A PROGRESS REPORT ON THE DEVELOPMENT OF METHODS FOR PREDICTING SOIL MOISTURE CONTENT

by

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Conducted for

WATERWAYS EXPERIMENT STATION

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VICKSBURG, MISSISSIPPI

November 1951

FOREWORD

This report covers one phase of the over-all study to determine the relationship between trafficability of soils and the mobility of military vehicles. This phase is concerned solely with the development of methods for predicting soil moisture content for specific soils, vegetation, and weather conditions. The ultimate objective is to enable military planners to forecast trafficability of soil in strategic areas without resorting to physical tests.

The Waterways Experiment Station, in February 1951, requested the Forest Service, U. S. Department of Agriculture to assist in this phase. By mutual agreement, the first Forest Service studies were conducted on three sites near Vicksburg, Mississippi, which the Waterways Experiment Station was using for trafficability investigations.

It was further agreed that the preliminary investigations would serve as a pilot study for developing methods for predicting soil moisture content. On the basis of the findings the Waterways Experiment Station would decide on the practicability of methods and determine the feasibility of extending this study to other areas.

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SUMMARY

Methods of predicting soil moisture content were developed for three sites in the Vicksburg area, Park, Rifle and Mound. Park is an upland area with loessal silt loam soil and vegetation consisting principally of perennial grasses. Rifle is located on a second-bottom; the alluvial silt loam soil supports a dense cover of grass and weeds. Mound is a bottom land area with heavy clay soil and herbaceous vegetation mainly in weeds.

Basic data from which to develop prediction methods consisted of a daily record of soil moisture from April 1 to October 1, 1951, for each site and concurrent data on rainfall, air and soil temperature, humidity and wind movement. Development and density of vegetation were checked periodically. Soil studies included profile descriptions and determination of texture, bulk density, moisture content at wilting point and field capacity, and soil moisture -- tension relations.

The soil moisture record consisted of a daily inventory of soil moisture content at 8 to 10 depths in the upper 42 in. This record was obtained with the Colman soil moisture meter and fiberglas units.

According to the requirements of this study particular attention was given to the prediction of soil moisture content at the 6- to 15-in. depth. The amount of soil moisture accretion at this depth following rainfall was found to be dependent on the relation between storm size and available storage. Three classes were established to describe the relation. Class I included all storms with rainfall less than the available storage in the 0- to 6-in. soil depth. Class II included all storms

for which storage in the 0- to 12-in. depth was less than rainfall. Class III included all storms with rainfall more than available storage in the 0- to 6-in. depth but less than that in the 0- to 12-in. depths.

The prediction of accretion in the 6- to 15-in. depths for Class I was that no significant accretion would occur; and for Class II storms, accretion would very nearly equal available storage. The prediction method for Class III consisted of subtracting the moisture retained in the 0- to 6-in. depth from "through rainfall" and apportioning the remainder to 3-in. layers of the 6- to 15-in. depth according to an available storage-accretion relationship.

Depletion curves in the soil moisture record were very similar throughout the entire period. Average depletion prediction curves were developed for each 3-in. layer from 0 to 15 in. Depletion rates, in general, were exponential in form with rates of loss tending to decrease with depth. No relation was found between depletion rates and air and soil temperatures, humidity, wind and vegetation composition.

The accretion and depletion methods were combined to predict soil moisture content for the period of record. Consistent agreements were obtained between actual and predicted values of soil moisture content.

THE DEVELOPMENT OF METHODS FOR PREDICTING SOIL MOISTURE CONTENT

INTRODUCTION

This is the first progress report on investigations being conducted by the Forest Service for the Waterways Experiment Station at Vicksburg, Mississippi. The purpose of this investigation is to develop methods for predicting soil moisture content.

The report covers the period from April 1 to October 1, 1951. Computations and analyses thus far completed are summarized and presented in general terms in this volume and in detail covering 13 separate phases in Volume II (Appendices A-M). Analyses completed thus far do not by any means exhaust the analytical possibilities, nor are all phases thus far studied reported herein. Investigations are being continued and other phases and analytical procedures studied. A final report covering an entire year's record will be presented at a later date.

Studies by the Waterways Experiment Station have shown that trafficability of a given soil will vary widely under different weather conditions. This variation has been related directly to soil strength and stickiness which in turn have been shown to be dependent on moisture content (3)*. Further studies have indicated that the ability of the soil to provide the necessary bearing and traction to support the traffic of military vehicles can be determined with a cone penetrometer by field reconnaissance parties. The relation between soil moisture and cone penetrometer values has been determined.

Often there is a great need for predicting trafficability of certain areas without resorting to any field reconnaissance. Moreover, for

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* Numbers in parentheses refer to literature cited.

tactical planning it is essential that some knowledge of most probable soil moisture content and hence trafficability be ascertained well in advance of any proposed action. It is under these conditions that the prediction of soil moisture becomes of paramount importance.

Purpose and Scope

The objective of this study is to develop methods for predicting moisture content of the soil at three sites located in the vicinity of Vicksburg, Mississippi.

Calibration and installation of field instruments were started in March 1951. Continuous, reliable daily records of soil moisture and weather factors became available in early April. Results presented in this report cover the period from about April 1 to October 1, 1951. This six-month interval may be considered to approximate very clearly the general active growing season in this locality. Results of data collected during cold, rainy, late fall and over-winter periods of high moisture content and low soil moisture extraction will be reported at the completion of a full year's record, shortly after April 1, 1952.

Methods and procedures developed on these sites, if practical, will be applied and tested in other areas. In a special meeting between representatives of the Waterways Experiment Station and Forest Service in July 1950, 25 sites including ten distinct soil types and three climatic conditions were selected for future study. It is believed that short cuts in field procedures and analytical methods developed in this pilot study can considerably reduce the time and labor originally thought necessary for completion of the over-all prediction study.

Past Work

The influence of climatic changes on soil moisture is under investigation by several agencies. The Forest Service has long been interested in the effects of native vegetation on the disposition of natural precipatation and the relation to soil moisture. Forest Service Experiment Stations located throughout the United States have been actively engaged in following the daily march of soil moisture through various seasons. (4, 6 and 9) Until recently, these studies involved the laborious methods of sampling soils for moisture content with geotomes or sampling tubes. The introduction of soil electrical units (2) in recent years has provided valuable help and new impetus to this research activity. It is now possible to follow the daily changes in soil moisture with a high degree of accuracy.

A thorough review of the literature fails to reveal any previous studies designed to forecast moisture content of soils. This may be due to laborious sampling difficulties prior to the introduction of electrical moisture measuring units as well as to a certain lack of interest in fundamental studies of this nature.

Forest Service research has also introduced a rainfall-simulator apparatus, generally called an infiltrometer (5). The employment of this equipment in numerous field studies has helped considerably in evaluating and understanding the infiltration process. The infiltrometer is also very useful in creating high moisture levels in the soil profile and may often materially speed up a particular investigation.

Factors affecting soil moisture

On the basis of recent research in the Department of Agriculture, particularly the Forest Service, certain basic concepts concerning soil moisture changes have developed.(8). A thorough knowledge of these fundamental relations is necessary for an understanding of prediction methods described in this report as well as for proper evaluation of results and their applicability to other areas.

Of all the climatic factors influencing soil moisture, precipitation is by far the most important. Plant growth is directly dependent on precipitation. In the arid and semi-arid West, where less than 20 in. of precipitation falls during a 12-month period, native vegetation usually consumes all of the available soil moisture by late summer. Likewise, except in certain local areas, in the humid eastern United States soil moisture accretion in the summer to the plant root zones seldom exceeds soil moisture depletion.

Precipitation is also one of the most variable of climatic factors. Yet, year in and year out, rainfall in any given region ranges between certain limits and does not differ sufficiently to alter appreciably vegetal cover, the relation between vegetation and soil moisture, and the resultant similar pattern of the march of daily soil moisture. During dry years the number of moisture accretions will be few and of low magnitude and the periods of moisture depletion prolonged; in wet years the periods of moisture accretion will be many but because rates of depletion are directly dependent on soil moisture content, the soil occupied by roots will usually be dried out by the end of the growing season. Another important fact concerning precipitation is that during

the year there is a preponderance of small storms and those of large magnitude occur infrequently. Therefore, repeated wetting of the upper zones occurs more frequently than at the deeper horizons.

Moisture accretion to the soil results mainly from rainfall not intercepted by vegetation but absorbed by the surface soil layers. Condensation may add slight amounts of water to the soil but these increments are negligible in relation to year-long precipitation. Infiltrated water almost completely fills the pore spaces in the upper soil layers prior to downward movement. As additional water infiltrates, the free water (under low energy) drains downward by gravity. Downward water movement occurs as a distinct wet front moving into the drier soil until free water is no longer present. This is the general pattern of moisture movement which occurs for most soils during and immediately following rainfall.

In addition to this fairly rapid movement, there is slow movement of water due to several factors. Capillary movement of water, for instance, usually called capillary conductivity or transmissivity, occurs at a slow rate but may be appreciable over a period of several months or more. Differential soil thermal conditions which are usually present may also result in capillary conductivity of water. Also the contact zones along the wet and dry fronts tend to equalize their moisture tensions resulting in some capillary conductivity of moisture into the drier soil. From the standpoint of moisture prediction and trafficability, such slow movements of water are unimportant.

The availability of water for plants is related to the suction force that holds the moisture within the soil mass. This in turn is

dependent on the forces that hold the moisture films around the soil particles or aggregates. This suction force is usually referred to as soil moisture tension and measured in atmospheres or equivalent heights of water or mercury. This force at field capacity may vary between 1/3 and 1/10 atmosphere (5 and 1.5 lb per sq in.) of tension range. Below field capacity the force required to remove moisture from the soil increases rapidly with a decrease in moisture content. At the wilting point of most plants the moisture content expressed in terms of energy approximates 15 atmospheres (225 lb per sq in.), indicating the large force needed to remove moisture from a dry soil. Some plants are able to withdraw moisture when at tensions approaching 100 atmospheres (7), but the difference between amounts of water held between this and the 15-atmosphere tension is unimportant. The values of field capacity and wilting point in terms of energy are the same for all soils but the volumes of water involved may differ greatly.

Different soils retain different amounts of moisture under the same energy levels. This is due primarily to variation in the size of soil particles. At wilting point the soil moisture content of fine-textured soils is much greater than coarse-textured soils because, with a preponderance of small size particles, the surface area for water absorption is much greater. However, regardless of particle size, film thicknesses are the same for similar energy levels.

The soil acts as a reservoir holding water in the pore spaces between the soil particles. The capacity of this reservoir depends largely upon the texture of the soil. The following table gives some idea of the

absolute quantity of water retained in the upper foot of soils of different texture. The soils are listed in order of coarseness of texture, the coarsest soils being listed first.

Soil Texture	Inches of Water Retained per Foot of Depth* At Field Capacity	At Wilting Point	Available to Plants
Hanford loamy sand (Calif)	1.5	0.6	0.9
Hanford sandy loam (Calif)	1.7	0.6	0.9
Hanford fine sandy loam (Calif)	2.3	0.7	1.6
Lewisville silty clay (Texas)	3.2	1.0	2.2
Martinez clay (Texas)	5.2	2.7	2.5

Generally, the fine-textured soils retain greater quantities of water at both field capacity and wilting point and also store greater quantities of moisture for plant growth as their spread between field capacity and wilting point is greater.

Moisture is extracted from the soil by two processes: evaporation and transpiration by plants. Only the combined losses need be evaluated for prediction purposes. Evaporation extracts moisture from the soil in layers starting at the surface and extending downward. The rate of this loss decreases as the depth of dry soil increases. Except where the capillary fringe of water table is near the soil surface, losses from evaporation alone are small below the 18-in. depth. In marked contrast, soil moisture extraction by plants occurs throughout the soil zone

* Dortignac, E. J. Dry-farming possibilities for Guayle in California (processed) Emergency Rubber Project Report 1945.

Dortignac, E. J. The range in moisture conditions suitable to tillage and planting operations on fine textured soils of the outwash and residual plains region of Texas (office report) Emergency Rubber Project 1944.

occupied by roots. When moisture and temperature conditions are favorable the extraction may occur throughout the entire root system at the same time. However, the reduction of root density with depth may result in slower rates of moisture depletion at lower depths. Evaporation and at times differential soil temperatures also affect the rate of moisture losses but the amount of root contact with the soil is the dominant factor influencing moisture extraction rates below the 18-in. depth.

Unless altered by man there is but little change in the types and amounts of native vegetation from year to year. The natural but minor changes that do occur have but little effect on moisture losses and for practical purposes of long term prediction can be ignored. The relative constancy of this vegetation factor from year to year results in a repeated pattern of soil moisture depletion.

Once the growing season commences the rate of moisture extraction from the soil increases rapidly over that occurring in the more or less dormant or inactive growing season. Year after year on well vegetated soils two definite evapo-transpiration periods occur: one of high soil moisture extraction during the active growing season, and the other of relatively minor moisture losses during the remaining period. There also exist two transition periods, winter-spring and fall-winter, but these are usually of short duration. It is well to note that if vegetation is damaged so as to reduce transpiration, then moisture losses from the soil are slowed down regardless of climate or season.

In general, soils with perched water tables or slow internal drainage react similarly to those without these characteristics. The main difference being that the slow internal drainage or presence of a

capillary fringe results in appreciable quantities of water remaining above field capacity. This water under low energy usually remains for prolonged periods during the inactive growing season as transpiring plants are usually the most important source of moisture extraction.

DESCRIPTION OF EXPERIMENTAL AREA

The three sites under study are Park, Rifle and Mound. Park site is located in the Vicksburg National Military Park about five mi north of the Waterways Experiment Station on the loessal bluffs east of Vicksburg. Rifle site, on loessal outwash, is located about two mi west of the Waterways Experiment Station. Mound is on bottom land across the Mississippi River in Louisiana some eight mi west of the Station. Mound and Rifle sites are located adjacent to areas previously tested for trafficability with vehicles (Appendix A).

Climate

The Vicksburg area is within the Gulf Coastal Plain physiographic province with the main sources of precipitation coming from the Gulf of Mexico. The climate is sub-tropical, characterized by hot, relatively dry summers and wet, moderately cool winters. The region has two rainy seasons, one over-winter period from November to April and another during July and August. Between these two wet seasons are the fall, and late spring-early summer dry seasons. The driest season usually occurs between middle September through October and a minor dry spell is usual in May and June.

The early part of the April 1 to October 1 period is characterized by occasional extra-tropical storms passing usually north of this area but resulting in general frontal rains. Scattered thundershowers occur from June until middle September. On rare occasions, tropical hurricanes from the Gulf of Mexico may move northward up the Mississippi Valley

and produce heavy rain.

The period of study, April 1 to October 1, varied from the normal climate of the area, particularly in regard to rainfall (Appendix C). May, with only a little more than one-half in. of rainfall, was drier than average: only two other times since 1900 has the total for May fallen below one in. August was also exceedingly dry with only only one-third of an in. of rainfall at Park site compared with the fifty-year average of 3.22 in. Rifle and Mound received about half of the normal for August.

September was considerably wetter than normal with over 5 in. recorded at each site. This was only the fourth time since 1900 that over 5 in. of rain fell in this area during September.

During the April 1 to October 1 period rainfall occurred on 41 days at Park and Rifle and on 34 days at Mound. Amounts of rainfall received at these three sites were quite variable. The greatest difference in rainfall occurred on July 28 when over 2.5 in. fell at Park, about 2.0 in. at Rifle and 0.5 in. at Mound.

Rainfall intensities in the Vicksburg area were generally relatively high between April 1 and October 1, particularly during the period of thundershowers. From 10 to 30 per cent of the rainfall in storms exceeding 0.25 in. fell at rates above two in. per hr, and approximately 70 per cent at rates above 0.50 in. per hr. Intensities of 4 to 7 in. per hr for 2- to 10-minute intervals were recorded several times during the summer.

Air temperatures at the three sites were reasonably similar. Summer temperatures were higher than normal. Daily maximum temperatures averaged

almost two degrees above normal in July and over six degrees above normal in August, breaking the 50-yr average at the Vicksburg Weather Station for the latter month. Extreme air temperatures at the sites were 103°F at Park on September 1 and 30°F at Rifle on April 17.

Average daily soil temperatures at the sites followed the general pattern of air temperatures. Maximum soil and air temperatures occurred from August 3 to September 4. Greatest variation in soil temperature occurred at the surface decreasing with increase in depth. Soil temperatures at Park and Mound were similar but Rifle averaged two to three degrees lower.

Humidity and wind records were only obtained during the latter part of this study (Appendix C). However, the records indicate that humidity was highest at Rifle and lowest at Mound. Wind velocities were higher at Mound than at Rifle. No wind records were obtained at Park.

Soils

The experimental sites are located in both upland and bottom land areas. The soil at Park site is an upland loessal soil classified as Memphis silt loam. The Rifle site is on an alluvial terrace derived from loessal outwash material originating probably from Memphis silt loam surface soil. The soil at Mound is a Sharkey clay, an old flood-plain deposit (Appendix D).

Little profile development occurs at Park, the soil being uniformly light-brown in color with gray-brown mottling beginning at 12 in. and increasing with depth. The weakly granular structure at the surface continued throughout the profile with some tendency towards larger

aggregates at depths below 4 ft.

The profile at Rifle is very similar to that at Park, the chief difference being in its dense, less permeable layer at 12-20 in. Weakly angular aggregates are present to a depth of 30 in. Below this depth, no structure is evident.

At Mound the soil progresses in color from gray-brown in the upper foot to bluish-gray at 5 ft and back to gray-brown at 10 ft. Structure in the upper 5 ft is blocky but below 5 ft the structure is massive. The 3- to 21-in. zone was moderately compact to very compact.

In general, soil profile variation over each experimental area though greater than normally found on similar size sites did not differ sufficiently to separate into distinct areas for analytical study purposes. The sole exception, Rifle site, did require separate bulk density values for the pit and tier sides.

Textural variations within sites are small (Appendix D). The composite particle size distribution curves for the upper foot of soil at the three sites are presented in Figure 1. These curves indicate that the loessal materials at Park and Rifle are reasonably similar with the water-deposited Rifle soil having a higher concentration of coarser particles. However, at both sites silt content approximates 85 per cent and clay 10 per cent. These curves are very similar to those developed for loessal soils in this region by U. S. Department of Agriculture soil surveys.

The particles size-distribution curve for the soil at Mound is distinctly different than for the loessal soils. The clay content exceeds 30 per cent, about three times as much clay as found on the loessal

soils. Sand content in this and the other soils is about the same, approximating 5 per cent.

Soils at all three sites vary in bulk density (volume weight) with depth and moisture content (Appendix H). At 20 per cent moisture content by weight, bulk densities of the surface 3 in. of soil were 1.11, 1.30 and 1.52 at Park, Rifle and Mound, respectively; and for the 9- to 12-in. depth, in the same order, 1.42, 1.62 and 1.51.

A summary of soil moisture measurements at each site is given on Table 1. Note that the moisture content for each classification tends to progress in magnitude in order of Park - Rifle - Mound. Also, despite the greater moisture contents at Mound, the water available to plants (difference between field capacity and wilting point) is actually less at this area than at Park or Rifle.

Vegetation

The vegetation at all three sites is herbaceous. At Park, an upland site, the plant composition is largely perennial grasses; with *Paspalum dilatatum* (dallis grass), *Axonopus compressus* (carpet grass) and *Cynodon dactylon* (Bermuda grass) dominating. *Hordeum pusillum* (Barley grass) was the only annual grass of note. The numerous weeds that make up the remainder of cover are described in detail in Appendix E. In early April, the plant cover was mainly *Hordeum* and weeds. By summer, *Hordeum* matured and died, weeds decreased and perennial grasses became dominant. By October 1, *Paspalum* was the main plant cover. Grass leaves reached a height of 12 in. before mowed in late May and 10 in. prior to the second and third mowings in middle July and September. There

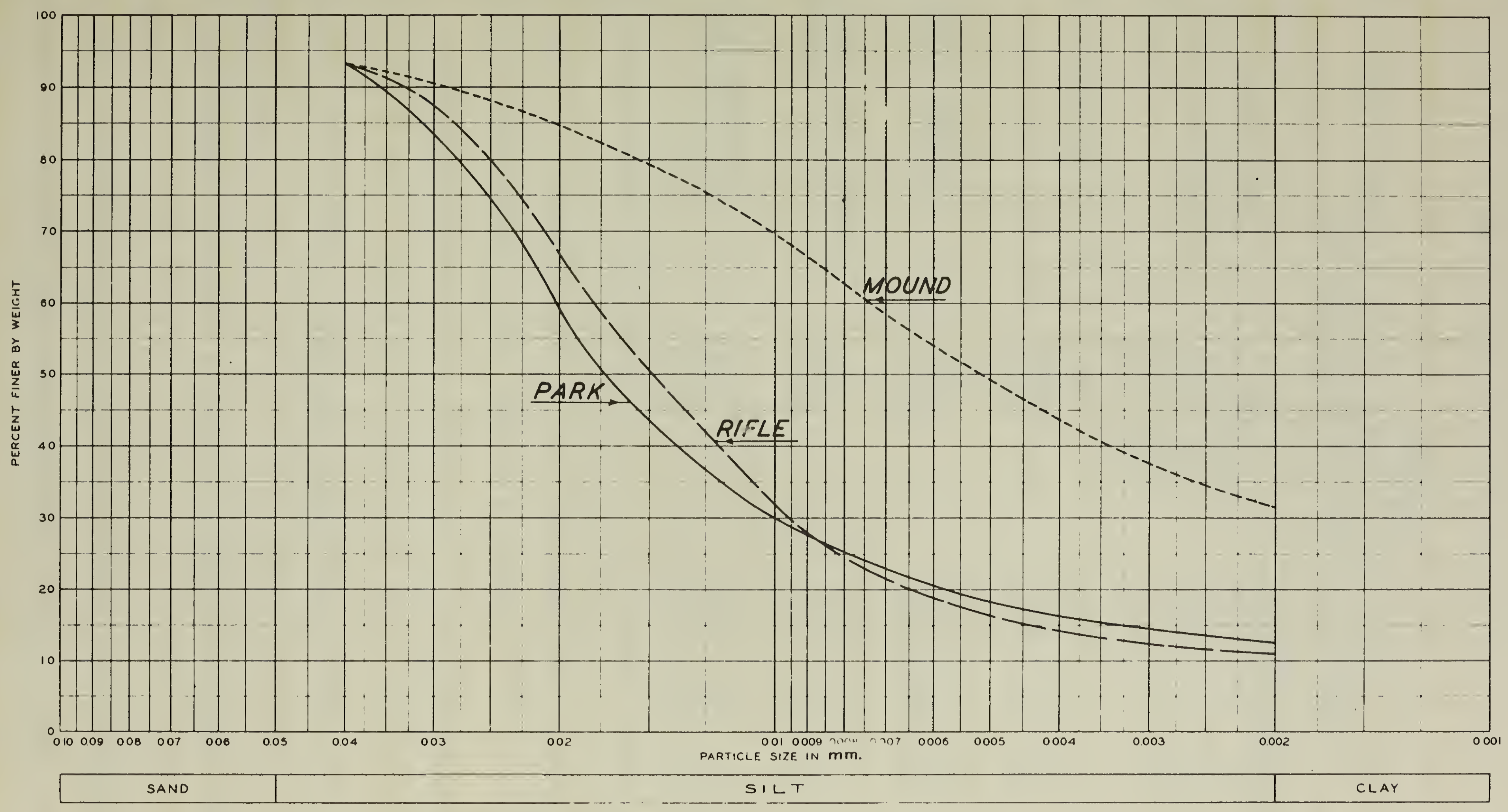


FIGURE I. AVERAGE TEXTURE FOR THE SURFACE FOOT OF SOIL AT ALL SITES

Table 1

SUMMARY OF SOIL MOISTURE MEASUREMENTS TAKEN AT PARK, RIFLE, AND MOUND SITES IN AREA-IN. OF WATER

Soil Measurement	Site	Soil Depth in Inches 0-3	3-6	6-9	9-12	12-15
Maximum field moisture content	Park (1A)	1.22	1.05	1.07	1.04	1.00
	Rifle (1B)	1.20	1.18	1.19	1.34	1.27
	Mound (1A)	1.26	1.36	1.39	1.39	1.36
4 cm of tension	Park	1.13	1.14	1.05	1.20	1.17
	Rifle	1.18	1.25	1.35	1.24	1.31
	Mound	1.22	1.32	1.40	1.47	1.56
60 cm of tension (Field capacity)	Park	1.06	1.10	.98	1.09	1.08
	Rifle	1.15	1.16	1.20	1.13	1.24
	Mound	1.17	1.27	1.34	1.37	1.40
Minimum field moisture content	Park	.38	.30	.32	.34	.33
	Rifle	.23	.31	.42	.51	.74
	Mound	.54	.70	.82	.74	.69
15 atmospheres (Wilting point)	Park	.41	.35	.36	.35	.46
	Rifle	.28	.33	.38	.49	.42
	Mound	.86	.94	1.01	.97	.82

was always an excellent cover of live and dead organic matter on this site with practically no bare soil at any time.

Flooding at Rifle during heavy rains had a marked influence on the plant composition. During the early spring three-fourths of the plant cover was weeds, mainly, Trifolium repens (white clover) and Rudbeckia amplexicaulis (blackeyed susan). As the early spring weeds matured and died the perennial grasses, dominated by Holcus halpensis (Johnson grass) moved in.

In the early spring this site was flooded twice. Consequently rapid plant growth did not begin until mid-April. Johnson grass started growing

rapidly about this time with other grasses beginning rapid height growth about ten days later. Height growth was completed by mid-June. Thereafter, grasses matured and kept flowering throughout the season. In August, the grasses dried considerably and reached a half-green state. With resumption of rains in September regrowth started at the base of grass plants.

Mound is also a bottom land site but on clay soil that has a low capacity for available water and a high rate of evaporation due to the large cracks that develop during drying of the soil. The vegetation at this site is composed largely of weeds: Aster sp, Iva caudata, Mimosa sp and Trifolium repens (white clover).

In mid-April, about one-fourth of the site area was bare, about one-half covered with organic materials and the remaining quarter in live weeds and annual grasses. By the end of April Holcus comprised one-fourth of the vegetal cover. In May, grass density decreased and weed cover became dominant until on July 11, weeds comprised three-fourths of the vegetation cover. On this date, exposed soil was reduced to 5 per cent of the area but the August and September drought increased bare soil to about 20 per cent. Vegetation was growing vigorously by mid-April; Johnson grass was 5 in. tall and Aster somewhat less. By June, Holcus was slightly over 2 ft and reached a height of 3 ft in mid-July. Mimosa, Aster and Iva reached their maximum height growth (15 to 21 in.) by mid-July. Vegetation continued growing until October 1 though greatly retarded during the late summer drought.

As soil moisture depletion or drying rates are dependent principally on transpiration and since transpiration is dependent on the extraction of

moisture by the root system, information on the below-ground portions of the vegetation is most important.

An estimate of the amount of roots present in the various soil layers was determined by washing them from foot-square soil blocks 3 in. deep. Rhizomes, bulbs, tap roots and trash were removed leaving only the fine roots. These are shown by 3-in. depths for all sites in Figure 2. Root density was considerably higher in the surface 3 in. of soil and decreased rapidly with depth. The following table gives root density as percentage occupancy of the total soil volume*:

Soil Depth (In.)	Park %	Rifle %	Mound %
0-3	1.67	.85	No sample
3-6	.46	.85	0.24
6-9	.25	.11	0.10
9-12	.18	.06	0.07
12-15	.13	.07	0.06

* Values were based on the assumption that fresh roots had fifty per cent moisture content and a specific gravity of 0.8.

DESIGN OF STUDY

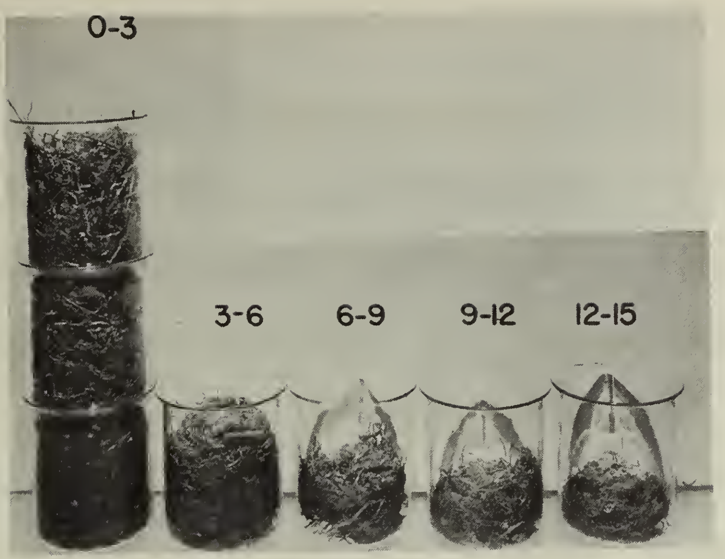
The basic data required for the development of methods for predicting soil moisture content were a daily soil moisture record of sufficient length to contain several soil moisture accretion and depletion periods, and concurrent data on all site factors that would conceivably affect soil moisture. With these data, the analysis consisted of correlating soil moisture content with the various site factors, selecting those factors which had the greatest influence, and using them to predict soil moisture content.

With these requirements, the first step was to install at each of the three sites sufficient equipment to provide a daily record of soil moisture at several positions and associated climatic data on rainfall, temperature, humidity, and wind movement.

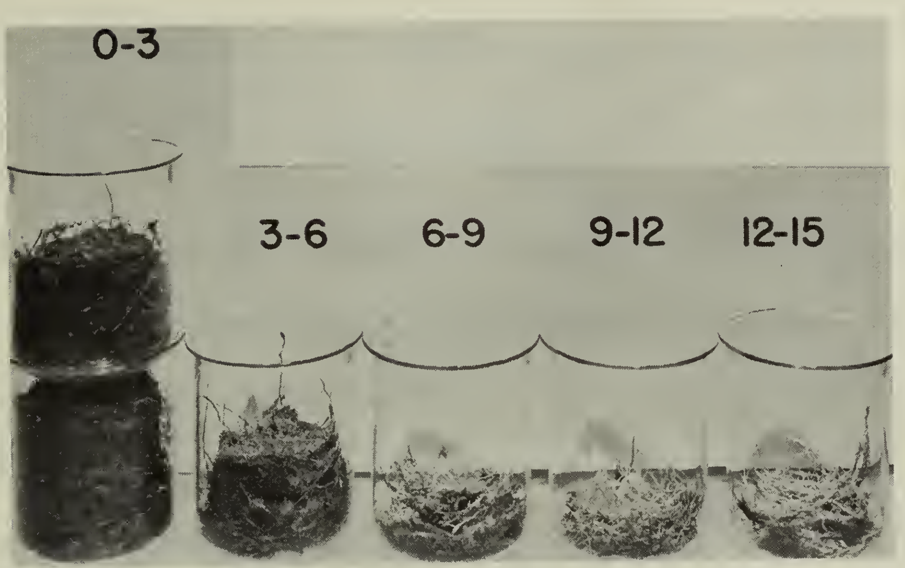
Soil Moisture Units

Colman soil moisture units were used for the measurement of soil moisture. Four tiers of units were installed at each site. Eight or ten units were installed in each tier. Units were installed at 3-in. depths to one ft and at 15, 21, 30 and 42 in. or at 3-in. depths to 2 ft and at 30 and 42 in. In addition to the Colman units, Bouyoucos nylon and plaster of Paris units were installed at Park and Mound as a basis for comparing the different types of soil moisture electrical units now available. Altogether 115 Colman units and 46 Bouyoucos units were installed at all sites.

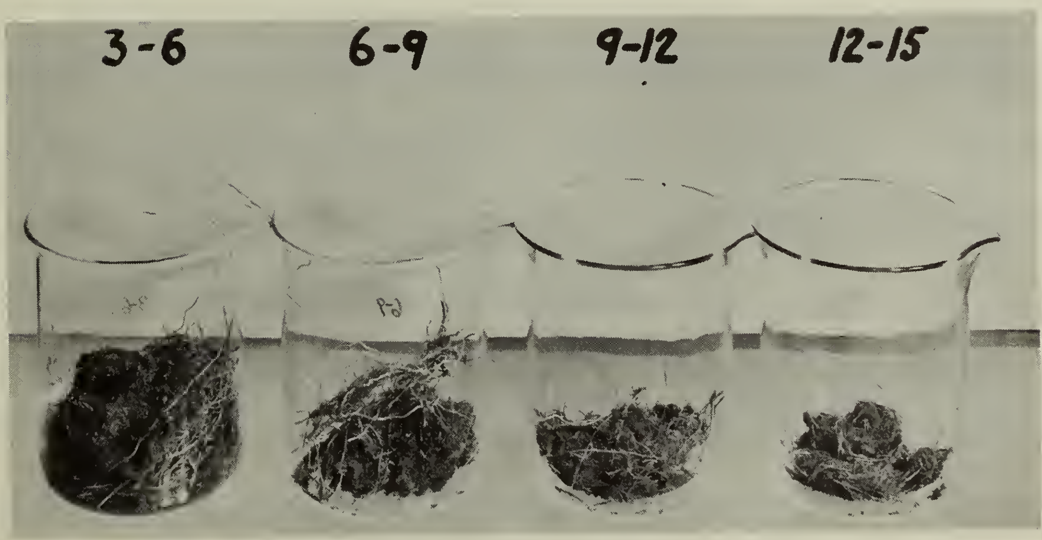
A 6-ft sq plot was laid out adjacent to each tier to provide for



Memphis Silt Loam



Vicksburg Silt Loam



Sharkey Clay

Figure 2. Root distribution in soils at Park, Rifle and Mound sites.

soil moisture sampling necessary for the calibration of the units. Each square foot was divided into four quarters giving a total of 144 sampling points in the plot. Soil moisture samples were taken with a King tube in duplicate to the same depths occupied by the units. Sampling points were randomized.

Soil moisture readings were taken once a day, occasionally more often when rain occurred. Soil moisture sampling was scheduled so as to obtain an adequate coverage of the range of moisture conditions encountered during the period of record.

Soil Studies

Proper evaluation of the daily soil moisture record required determination of several physical characteristics of the soil. Soil profiles at each site were studied and described during installation of units, volume weight sampling, and digging of wells. Soil texture was determined for each 3-in. layer to a depth of 12 or 15 in. Bulk density (volume weight) was determined for the same layers.

Soil moisture constants of field saturation, field capacity, and wilting point were measured for each 3-in. layer, from 0 to 15 in., with a tension table and pressure membrane cells. In addition, moisture contents over a range of tension from 0.1 to 15 atmospheres were measured to obtain soil moisture-tension relations.

Besides these studies, considerable effort was expended on the laboratory calibration of the Colman units. This included developing laboratory calibration curves for units installed in replicate soil samples taken with natural field structure from each of the depths

represented in the field installations. These units were inserted into the soil before cutting and removing cores. Still other laboratory calibration curves were developed for units that had been installed in the field in March and early April and removed after a 3-month period. Difficulty in obtaining agreement between laboratory and field calibration curves led to other studies: the effect of soil swelling on calibration; moisture gradients in laboratory samples during air drying and in drying in humid chambers; calibration curves for graded separates; and calibration curves for the fiberglass fabric used in the Colman unit.

Climatic Studies

Climatic instruments maintained by the Waterways Experiment Station previous to the Infiltration Project included a recording intensity gage, standard rain gage, and a thermograph at each site. Shortly after the project started, daily gears were substituted for the weekly gears in intensity rain gages. As fast as they could be obtained, hygrothermographs and anemometers were installed. Following is a list of climatic instruments and the date of installation:

Instrument	Park	Rifle	Mound
Standard rain gage	*	*	*
Recording rain gage	*	*	*
Thermograph	*	*	*
Hrgrothermograph	9/4/51	7/16/51	7/16/51
Totalizing anemometer (4 and 16 ft above ground)		7/23/51	7/23/51
Totalizing anemometer (8 ft above ground)		8/3/51	8/3/51

* Installed prior to initiation of Forest Service soil moisture study.

Vegetation

A study of the types, densities, and growth of vegetation at the three sites was made so that their effect on soil moisture content could be evaluated (Appendix E). In the spring, the vegetation at each tier was described about once a week according to composition, density, height, vigor and stage of development. Later in the season, during periods of slower growth, analyses were made about once a month. Vegetation on each infiltration plot was also described.

Plant cover density, an estimate of the area of the aerial herbage projected on the ground, was determined by ocular estimate at the tiers and expressed as a percentage of the total surface area. On the infiltration plots, percentage estimates of grass, weeds, litter and exposed soil were made with the aid of a wire grid placed across the plot.

Wells and Tensiometers

Two wells were dug at Rifle and Mound in the latter part of May to a depth of approximately 10 ft to determine the effect of the water table on soil moisture. Daily readings were taken of the water level throughout the period of record (Appendix F). No wells were dug at Park as the water table in that area was too far below the surface to have any effect on soil moisture in the upper 42 in. of soil.

Tensiometers were installed at depths of 21 and 42 in. at both Rifle and Mound to study the movement of water at energy levels less than 0.8 atmosphere.

Infiltration Studies

Infiltration rates were determined at each site during April and May.

The Rocky Mountain Infiltrometer and procedures described by Dortignac (5) with certain modifications were used in this phase of the study (Appendix G). Tests were conducted on 20 infiltrometer plots at Park, 8 at Rifle, and 8 at Mound. In late August and early September an additional 4 plots were tested at Park to check the effect of low summer moisture conditions on infiltration rates (Appendix G).

DEVELOPMENT OF MARCH OF SOIL MOISTURE

The development of methods for predicting soil moisture content required first of all, for basic data, a daily record of soil moisture taken at depths pertinent to the trafficability requirements. Daily readings of resistances were started as soon as the units were installed in order to obtain as lengthy a record as possible. Translation of these resistances into moisture contents required first, the development of calibration curves giving the soil moisture content - ohms resistance relationship, and second, providing means for expressing soil moisture volumetrically.

Calibration curves were based for the most part on data obtained from soil moisture sampling in the plots adjacent to the tiers of units, the soil moisture value at each depth being plotted against the resistance measured at the corresponding time for the same depth. Sufficient data of these kind were obtained to cover adequately the entire range of soil moisture content experienced during the period of record. Individual curves were derived for each Colman unit installed in the field. Laboratory calibration data (Appendix J) were used to help define the shape of the curves and the position of the wet and dry ends. A tabular presentation of each calibration curve was prepared to facilitate changing daily resistances to soil moisture.

Density Measurements

Information on bulk density (volume weight) was required to convert moisture contents in per cent by weight obtained in field calibrations to

rainfall equivalent in area-inches. Accordingly, bulk density samples were taken at each site to a depth of 12 to 15 in. by several methods and over a range of moisture contents from approximately wilting point to field saturation (Appendix H). The infiltrometer was used to saturate the sampling areas.

A partial summary of the results is given in Table 2. As indicated, bulk density was found to vary with depth and moisture content. Roughly, it decreased 0.01 of a unit per one per cent increase in soil moisture content.

Bulk densities were used to convert all soil moisture contents of the calibration data from per cent by weight to area-inches and the final calibration curves were expressed in this unit.

Table 2

VARIATION OF BULK DENSITY WITH DEPTH AND MOISTURE CONTENT

Depth In.	Location	Bulk Densities, Soil Moisture Content (Per Cent) 10	20	30	40
0-3	Park	1.312	1.203	1.095	.986
	Rifle	1.400	1.300	1.210	1.110
	Mound	1.735	1.518	1.301	1.084
3-6	Park	1.451	1.370	1.290	1.209
	Rifle	1.510	1.420	1.320	1.230
	Mound	1.760	1.585	1.410	1.235
6-9	Park	1.542	1.374	1.209	1.042
	Rifle	1.580	1.480	1.390	1.290
	Mound	1.760	1.585	1.410	1.235
9-12	Park	1.542	1.374	1.209	1.042
	Rifle	1.710	1.610	1.520	1.420
	Mound	1.646	1.507	1.368	1.229

Daily Soil Moisture Record

With completion of the density measurements and calibration curves, the daily record of resistances obtained at each tier and unit was converted to soil moisture content in inches. The march of soil moisture was then plotted for each tier by each 3-in. depth from 0 to 15 in. Figure 3 illustrates the resultant curves for Rifle, 3- to 6-in. depth. For purposes of accretion and depletion analysis the mean daily value was also calculated for each depth and site. The daily mean value for three depths and associated climatic factors are given in Figures 4, 5 and 6 for Park, Rifle and Mound, respectively.

PREDICTION OF SOIL MOISTURE ACCRETION

Due to the peculiar conditions associated with the prediction sites, the development of a methodology for prediction of soil moisture accretion at the three sites proved to be more complicated than would normally be expected. At Park, the Vicksburg National Military Park requirement that all instrumentation be placed below the soil surface introduced errors in reading resistances during and immediately following wet weather. In addition, soil compaction and disturbance, due to the presence of a CCC Camp on this area during the thirties, caused a greater than normal variation in infiltration rates. At Rifle, flooding by overflow of Stout's Bayou or by local runoff from the adjacent road and levee introduced additional complications. At Mound, the large soil cracks developed during soil drying periods often led rainfall to the fiberglass units without the adjacent or upper layers of soil being wetted, thus distorting the soil moisture record.

Some of these special conditions may occur throughout all land areas; yet, their extent on an areal basis is usually small. Because it is usually more practical to base predictions on the average or most prevalent conditions and adjust for special conditions where necessary, the soil moisture record was adjusted when possible so that it would more closely represent typical conditions. Adjustments were confined to erratic soil moisture values which could be corrected on the basis of the soil moisture record at adjacent tiers.

Because of the unwonted variation, errors involved in predicting soil moisture content on the three sites are probably the maximum that

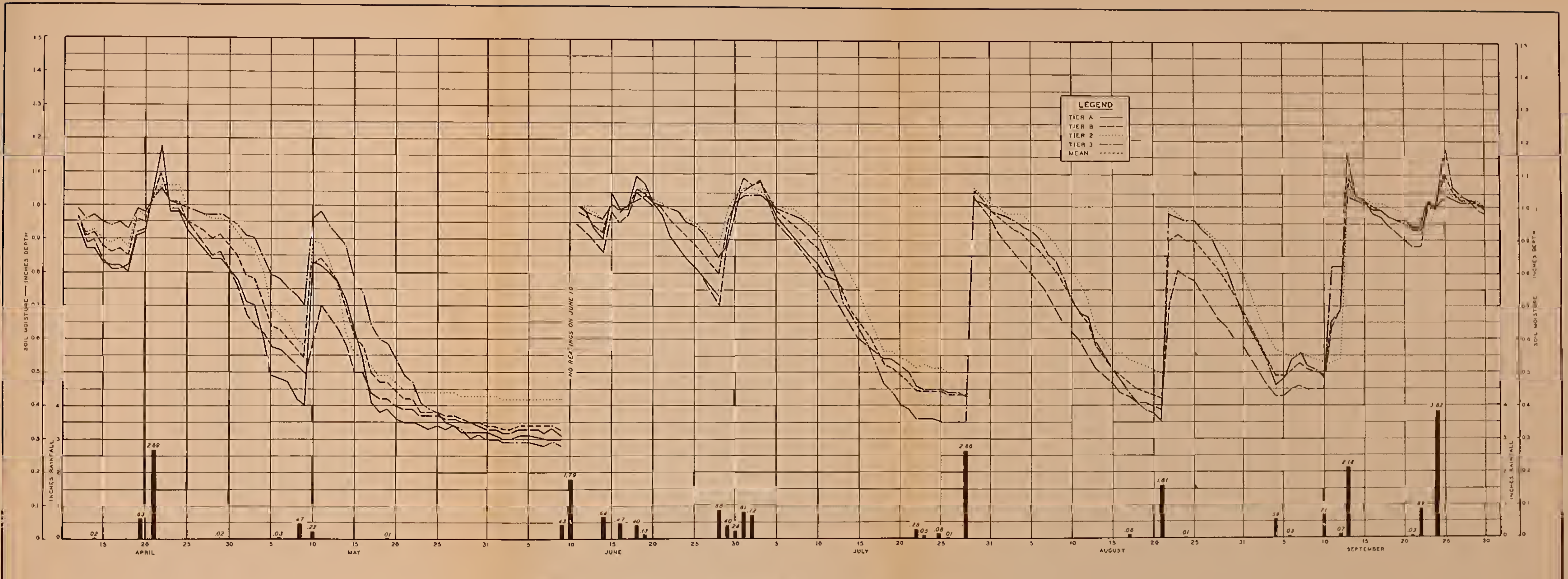


FIGURE 3. DAILY MARCH OF SOIL MOISTURE 3-6" AT RIFLE RANGE SITE

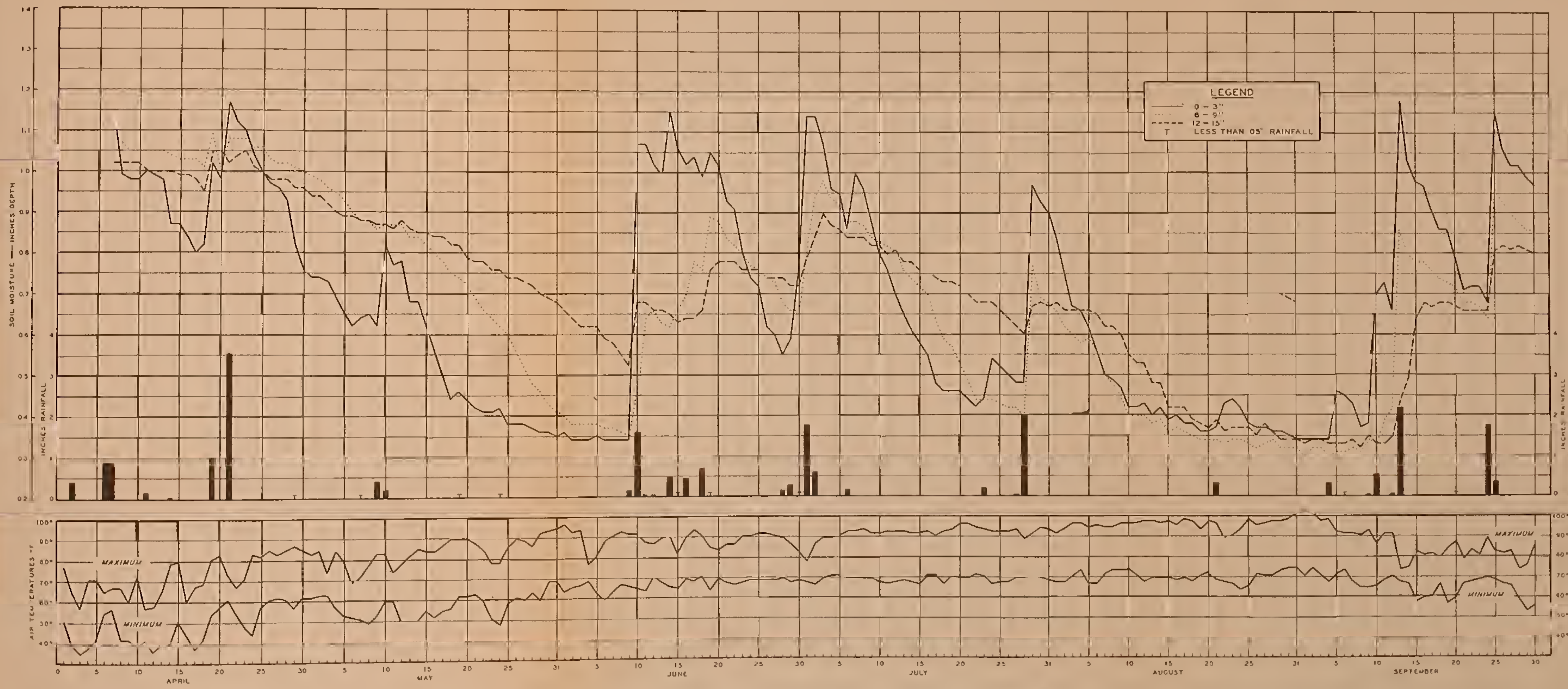


FIGURE 4. DAILY MARCH OF SOIL MOISTURE AND AIR TEMPERATURES AND RELATION TO RAINFALL DURING GROWING SEASON —— PARK SITE

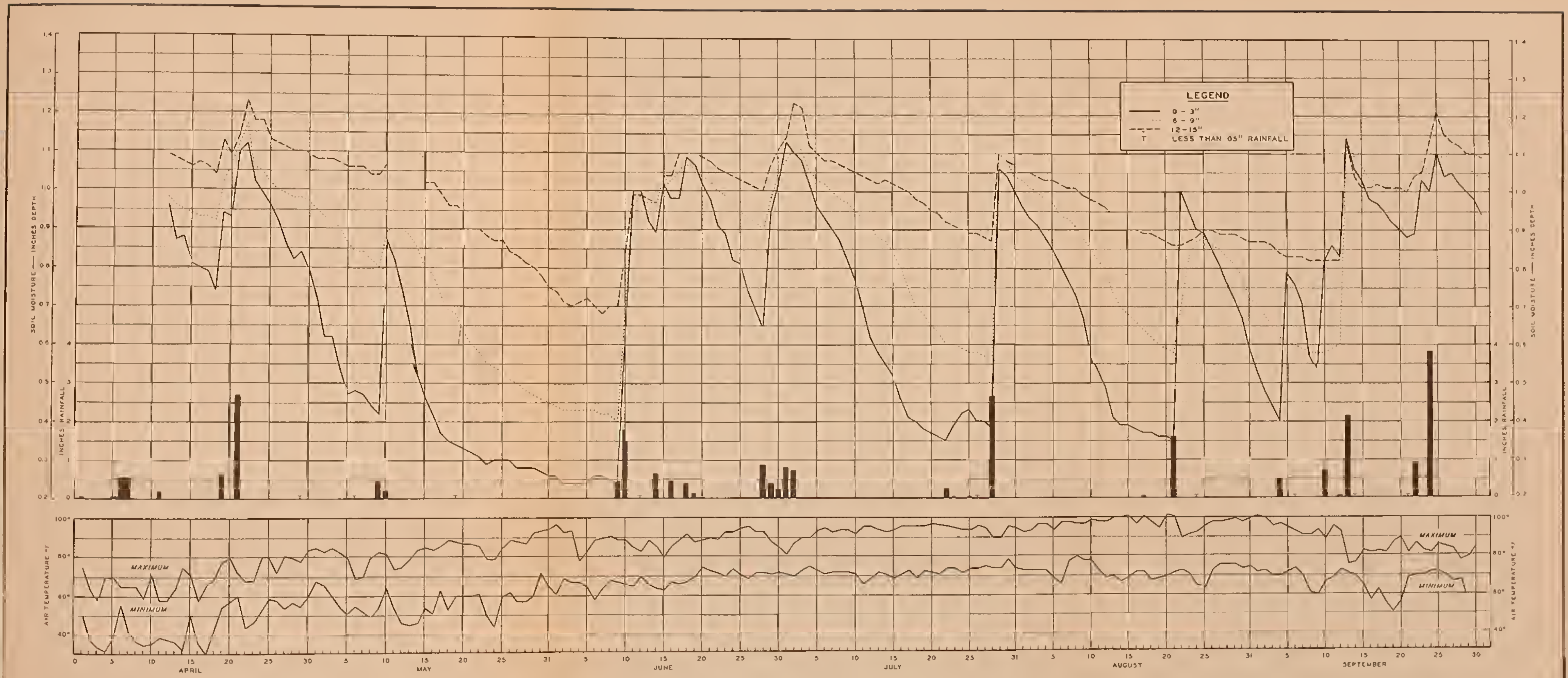


FIGURE 5. DAILY MARCH OF SOIL MOISTURE AND AIR TEMPERATURES AND RELATION TO RAINFALL DURING GROWING SEASON — RIFLE SITE

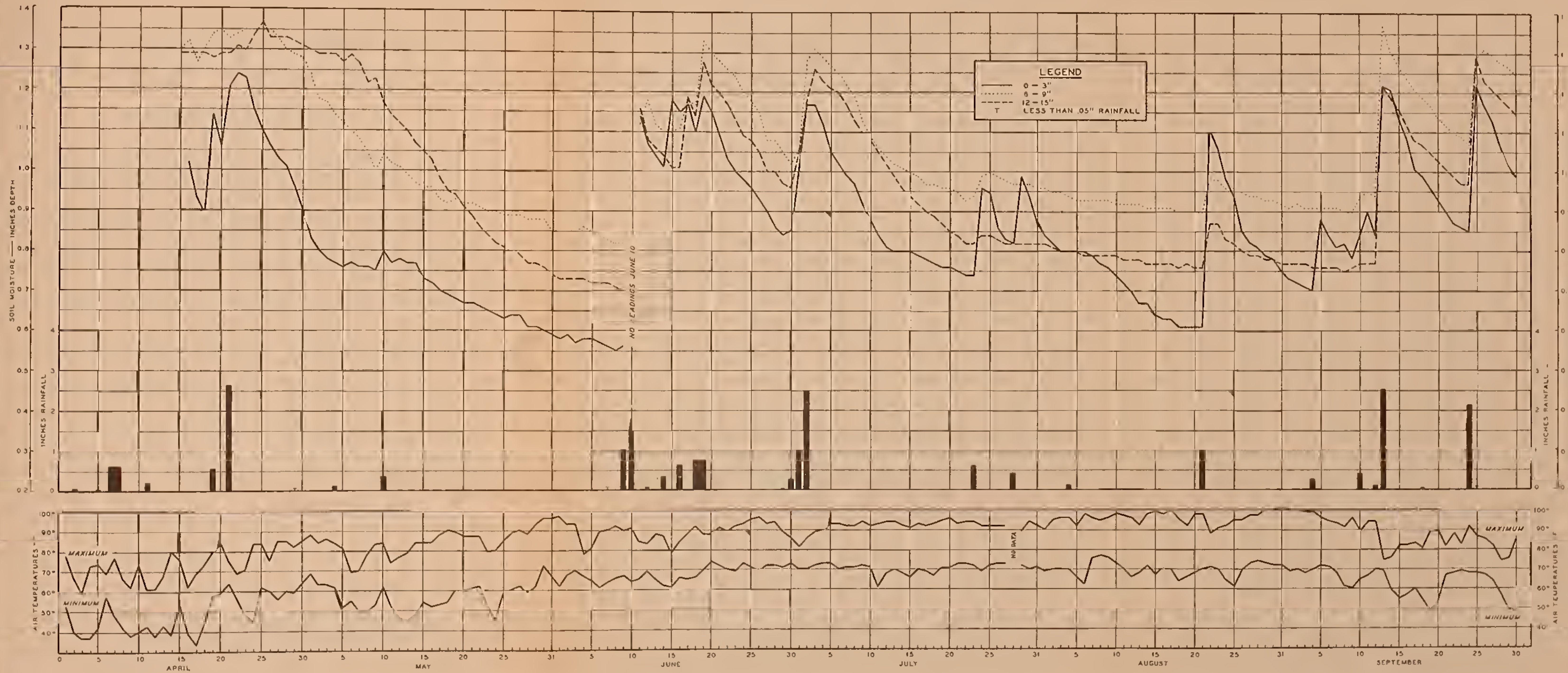


FIGURE 6. DAILY MARCH OF SOIL MOISTURE AND AIR TEMPERATURES AND RELATION TO RAINFALL DURING GROWING SEASON — MOUND SITE

would be expected in nature even under the worst conditions. In future work the element of site normality should be fully considered in the selection of experimental areas.

Infiltration and Interception

Exploratory analysis early established that the amount of soil moisture accretion during any one storm depends largely on the amount of storage space in the soil available for moisture. Infiltration rates, determined with the infiltrometer during April and May, were low for all sites. Despite these low rates, the soil moisture record during the summer months indicated that when sufficient storage was available little runoff occurred even from high intensity storms. This anomaly was explained by infiltrometer runs made in August and September which gave much higher rates than those made in the spring (Appendix G). Difference in the rates between the spring and summer runs was due to the difference in the amount of storage space available before the run. During the spring runs the soil was wet and had little available storage space. Later in the season, more storage was available, and, because infiltration rates did not limit utilization of the storage space, soil moisture accretion was much greater.

Before accretion could be predicted, consideration had to be given to the amount of rainfall intercepted by vegetation which is unavailable to accretion. These values were determined from retention storage data of the infiltrometer runs, and from soil moisture accretion data (Appendix K). Data from the latter were obtained only from those storms in which rainfall exceeded estimated interception and for which no surface runoff

occurred. For these storms the difference between rainfall and accretion could be used as an estimate of interception. Interception values were estimated to be 0.15, 0.25 and 0.20 in. for Park, Rifle and Mound, respectively. Subtracting these values from storm rainfall gave a remainder termed "through rainfall".

Accretion and Available Storage

Accretion was calculated as the difference in soil moisture content before and after a storm. In most instances the soil moisture content determined at the first daily reading after the storm was used as the wet-soil value. Occasionally, readings on the second day following the storm were used in cases when on the first day, for instance, the switch box at Park had become too wet for reliable readings, or when rainfall at Mound had obviously run down a soil crack to wet a unit. Accretion was calculated for each tier and the mean value of the tiers computed for each 3-in. depth from 0 to 15 in.

Available storage space before a storm was calculated as the difference between actual soil moisture content and the comparable maximum moisture content for the period of record. For each depth, the available storage space was calculated for each tier and the average value for all tiers computed.

Storm Classes

During the period April 1 to October 1 there were 19 storms at Park for accretion analysis, 18 at Rifle, and 17 at Mound. Inspection of rainfall data of these storms and associated data on available storage

space and accretion revealed that, in relation to accretion, these storms could be classified according to the amount of available storage space and rainfall. When there was a relatively large amount of available storage in the upper 6 in. of soil and a small amount of rain, little or no accretion resulted below 6 in. Conversely when rainfall exceeded available storage space in the 0- to 12-in. depth, available storage below 6 in. tended to be satisfied. Intermediate between these classes were storms which had sufficient rainfall to satisfy available storage space in the 0- to 6-in. depth but not enough to satisfy that in the 6- to 12-in. depth. These three classes were used as the basis of the accretion prediction. Specifically, they were defined as follows:

Class I. Storms for which through rainfall is less than available storage in the 0- to 6-in. depth.

Class II. Storms for which through rainfall is greater than available storage in the 0- to 12-in. depth.

Class III. Storms for which through rainfall is greater than available storage in the 0- to 6-in. depth but less than available storage in the 0- to 12-in. depth.

Prediction for Class I and II Storms

The prediction for the Class I storms at each site was based on the average accretion, from all storms of this type, in the 6- to 9-, 9- to 12- and 12- to 15-in. depths. For each site this proved to be an insignificant amount both in regards to its magnitude and to its probable effect on trafficability. Average accretions for these three depths, in the order given above were 0.02, 0.01 and 0.00 in. at Park; 0.05, 0.06, and 0.04 in. at Rifle; and 0.03, 0.03, and 0.02 in. at Mound. For practical purposes, it may be assumed that storms of this nature have no effect on accretion

below 6 in.

The effect of Class II storms on accretion, on the other hand, may be considerable if there is a large amount of available storage. But whether there are large or small amounts of space available, the prediction is simple: accretion below 6 in. will tend to equal available storage.

For Class II storms the relation between accretion and available storage at the 6- to 9-, 9- to 12- and 12- to 15-in. depths at each site is given in Figure 7. At Park, April storms tended to satisfy all of the available storage space while the two storms that occurred later in the season did not. At Rifle, where natural rainfall on the plot was augmented by surface runoff, storms in Class II consistently tended to satisfy available storage space. The same relation held at Mound.

The fact that rainfall from Class II storms did not always completely satisfy available storage at the three sites was due in part to an overly long interval between the end of the storm and the meter reading, the use of maximum values of available storage space for summer-storm analysis derived from maximum moisture contents recorded in the spring, and the variation in depth of wetting in spring and summer which may have had some effect on degree of wetting (Appendix K).

However, as Figure 7 indicates, for practical purposes available storage may be said to be satisfied in the Class II storms. Thus, use of this storm classification simplifies the prediction of soil moisture accretion: for the first two classes the predictions are no accretion at depths below 6 in. (Class I), and accretion equal to storage space (Class II storms).

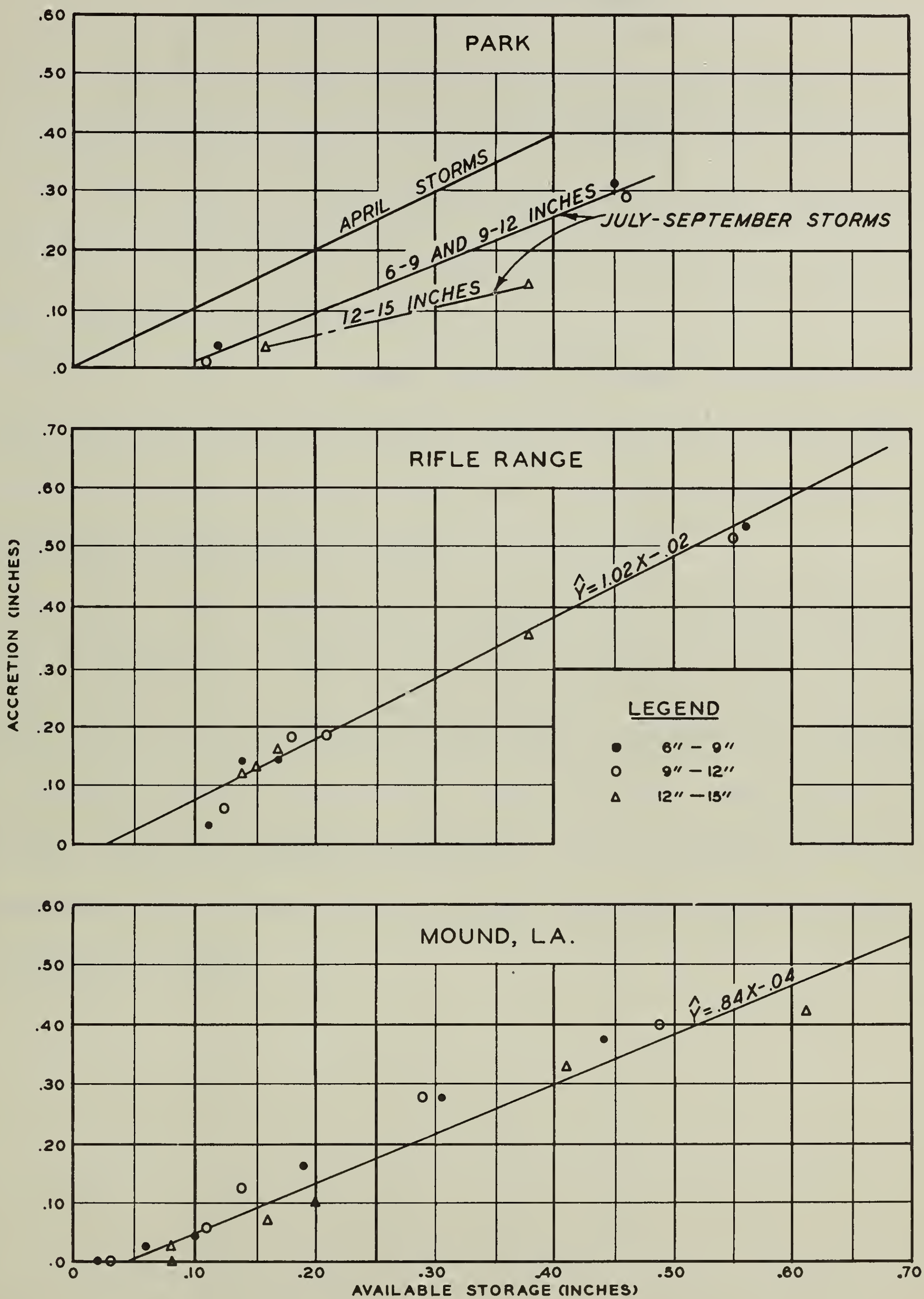


FIGURE 7. RELATION OF ACCRETION TO AVAILABLE STORAGE
CLASS II STORMS — 6-15 INCH DEPTH

Prediction for Class III Storms

The prediction of accretion for Class III storms involves two steps: (1), determining the precipitation available for accretion at the 6- to 15-in. depth (residual precipitation); and (2), apportioning the residual precipitation to the 3-in. depth classes by an available storage - accretion relationship.

Step (1): Since this class is partly defined by satisfaction of available storage in the 0- to 6-in. depth, accretion in this depth will be directly related to storage, Figure 8. Subtracting this accretion from through rainfall gives residual precipitation.

Step (2): With the residual precipitation, it is then possible to enter the abscissa of the figures given in Figure 9, and from the regression line read the estimated accretion, provided the available storage space is equal to or greater than that value encountered on the regression. If less storage is available, it is necessary to move down the regression line to the proper storage value and from that point read the estimated accretion.

DEVELOPMENT OF DEPLETION CURVES

The daily march of soil moisture shown in Figures 3 to 6 discloses a definite pattern of soil moisture extraction between rainstorms. Following each rain the rate of moisture loss was relatively rapid until soil moisture approached wilting point or at a tension of about 10 atmospheres. Thereafter, the rates of loss decreased until moisture content became relatively constant. At Park and Mound, rates of moisture loss in April in the deeper soil layers were lower than during the summer period.

The repeated and similar pattern of moisture losses during the active growing season became more evident by superimposing individual drying curves for a given soil layer on a similar graph to that shown in Figure 10. From 9 to 15 individual moisture depletion curves (the exact number depending on soil depth and site) were superimposed on the same graph by matching similar soil moisture contents. Moisture content on the day following a rainstorm coincided with day 1 on the abscissa only when a depletion curve started at the maximum moisture content of record. Matching individual drying curves showed reasonably close agreement. The maximum spread enveloping all depletion curves during the active growing season for a 3-in. soil layer amounted to only 0.14 in. (Appendix L).

Values for soil moisture depletion curves for each 3-in. soil layer at each site were determined by tabulating the daily soil moisture in area-inches for each drying period. Similar moisture contents were tabulated so that daily moisture contents matched as far as possible. Matching moisture contents by days was facilitated through use of the superimposed depletion curves. The arithmetic averages were calculated and these

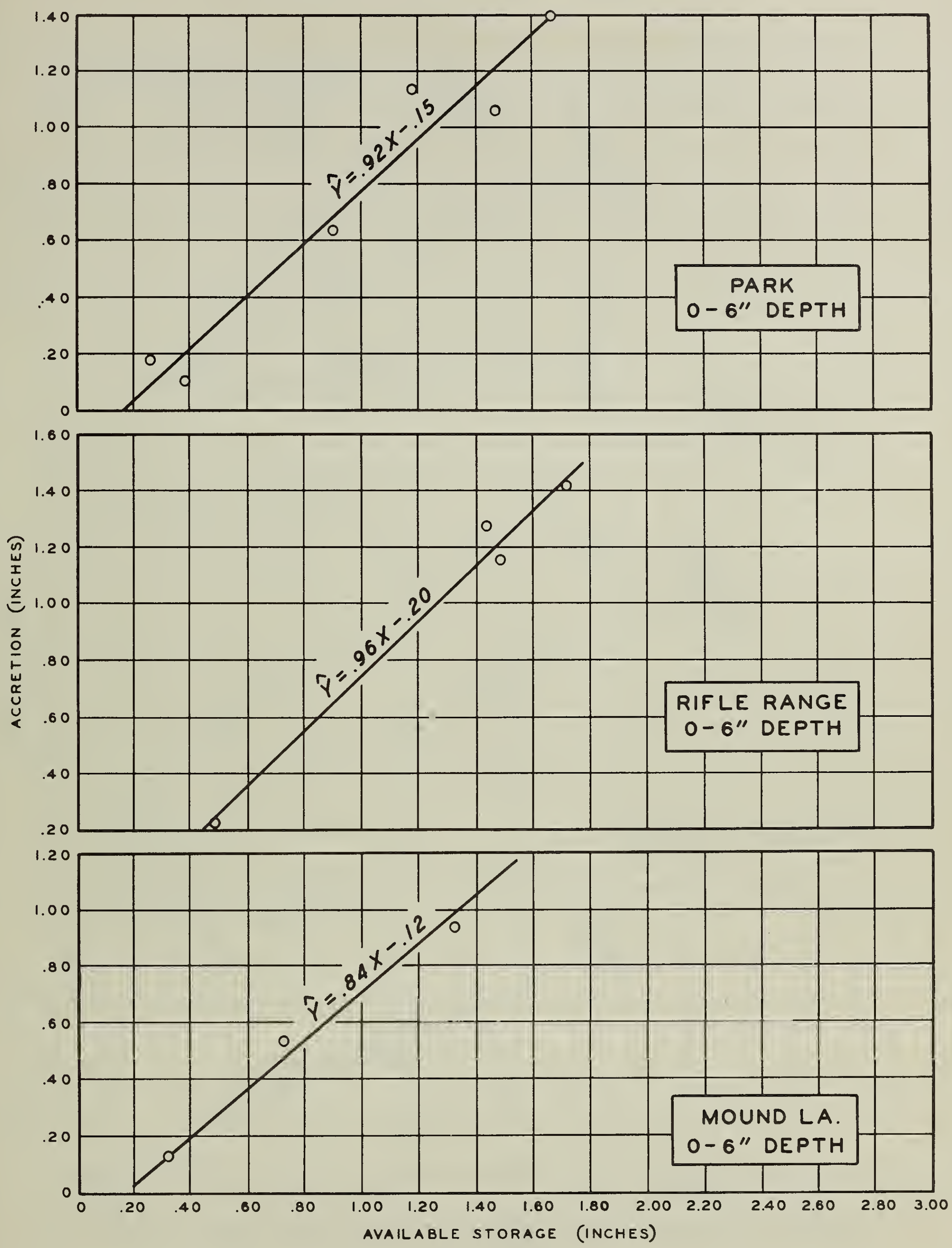


FIGURE 8. RELATION OF ACCRETION TO AVAILABLE STORAGE
CLASS III STORMS - 0-6 INCH DEPTH

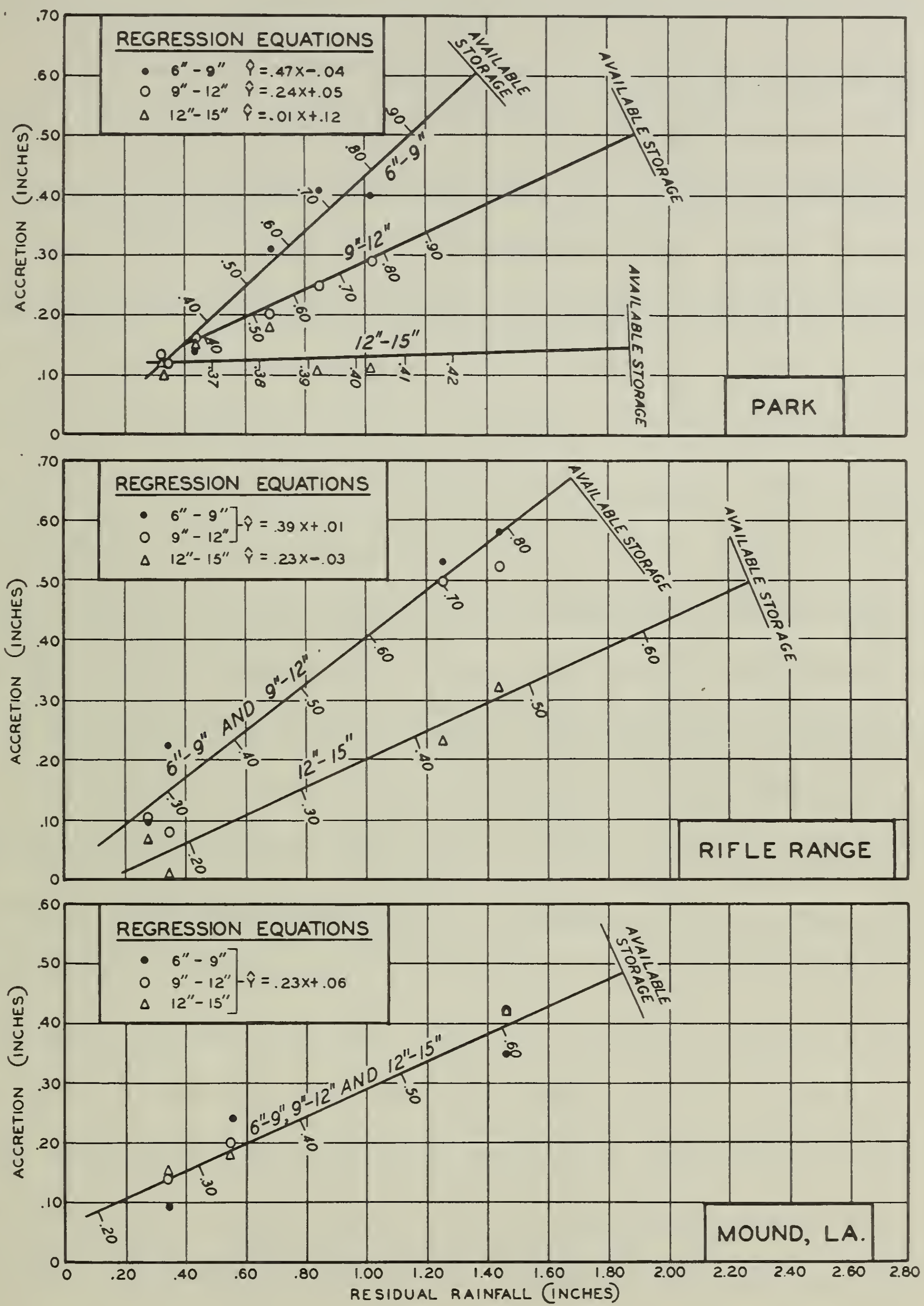


FIGURE 9. RELATION OF ACCRETION TO RESIDUAL RAINFALL
CLASS III STORMS

values plotted. The resultant curves are given in Figures 10-12.

The length of curves varied from 35 to 50 days, depending on soil depth. In general, there is considerable similarity between Park and Rifle depletion curves. At Mound site, the amounts of moisture loss are only about half of those at the other two sites. This is due to the much lower moisture capacity of Sharkey clay between field capacity and wilting point. This range of moisture, termed "available water" for plants, was only 2 in. in the surface 15 in. of soil. In marked contrast, Park and Rifle soils has 3- and 4-in. capacity for available water in the same depth of soil. This variation in opportunity for storage of available water resulted in differential seasonal moisture losses at the three sites. The total evapo-transpiration losses from April 1 to October 1 amounted to 13.1, 15.1 and 11.8 in. for Park, Rifle and Mound, respectively.

The rate of moisture loss was highest in the surface 3 in. of soil and diminished gradually with depth to the 15-in. zone at Park and Rifle. At Mound, this regular sequence of decrease in rate of soil moisture loss with depth was broken at the 1-ft depth. Soil between the 12- and 18-in. depth had a greater loss rate than that between 3 and 12 in. The diminishing rates of moisture loss with increasing depth are due mainly to evaporation, though transpiration may be important. Evaporation removed moisture from the soil in layers starting at the surface where the rate of loss is greatest and dimished gradually to a depth of 12 to 18 in. This would tend to give slower depletion rates with increase in depth. Transpiration losses are dependent on the ability of the roots to absorb soil moisture. The large decrease in fine (absorbing) roots from the surface to the 15-in. depth shown in Figure 2 may also reduce transpiration rates at lower depths.

The variation in the general pattern of decreasing rate of moisture loss with depth, at Mound, may be explained by the greater opportunity for evaporation at this site. The vegetation cover was thinner and more bare soil was exposed at Mound. Also, the heavy clay developed large cracks during drying thus exposing the deeper soil layers to the air.

Inspection of average depletion curves shown in Figures 10-12 brings out rather sharply the similarity between the maximum rates of moisture loss of the various curves. The portion of each depletion curve exhibiting the maximum rate of moisture loss is shown in Figure 13. These data show that the rate of moisture loss was very similar for all sites during these periods. Maximum losses of water at Park and Rifle occurred when soil moisture varied between about .3 and 5-10 atmospheres of tension and at Mound between .2 and 13-19 atmospheres, depending on soil depth.

The individual moisture contents for these portions of the depletion curves were averaged and a composite set of curves drawn for each soil depth. These data are presented in Figure 14. In general, the composite curves approach a straight line and have decreasing rates of moisture loss with soil depth.

The average depletion curves were divided into periods of similar moisture losses. In most instances, three periods were needed: low rates of moisture loss in the upper range of moisture; low rates of moisture loss in the lower moisture range; and maximum rates of moisture loss. At Mound, depletion curves were divided into 2 periods for all but the 9- to 12-in. depth. The average rates of moisture loss for these periods of extraction are given in Table 3. The summation of individual periods accounted for most of the over-all depletion period. At Park, in the

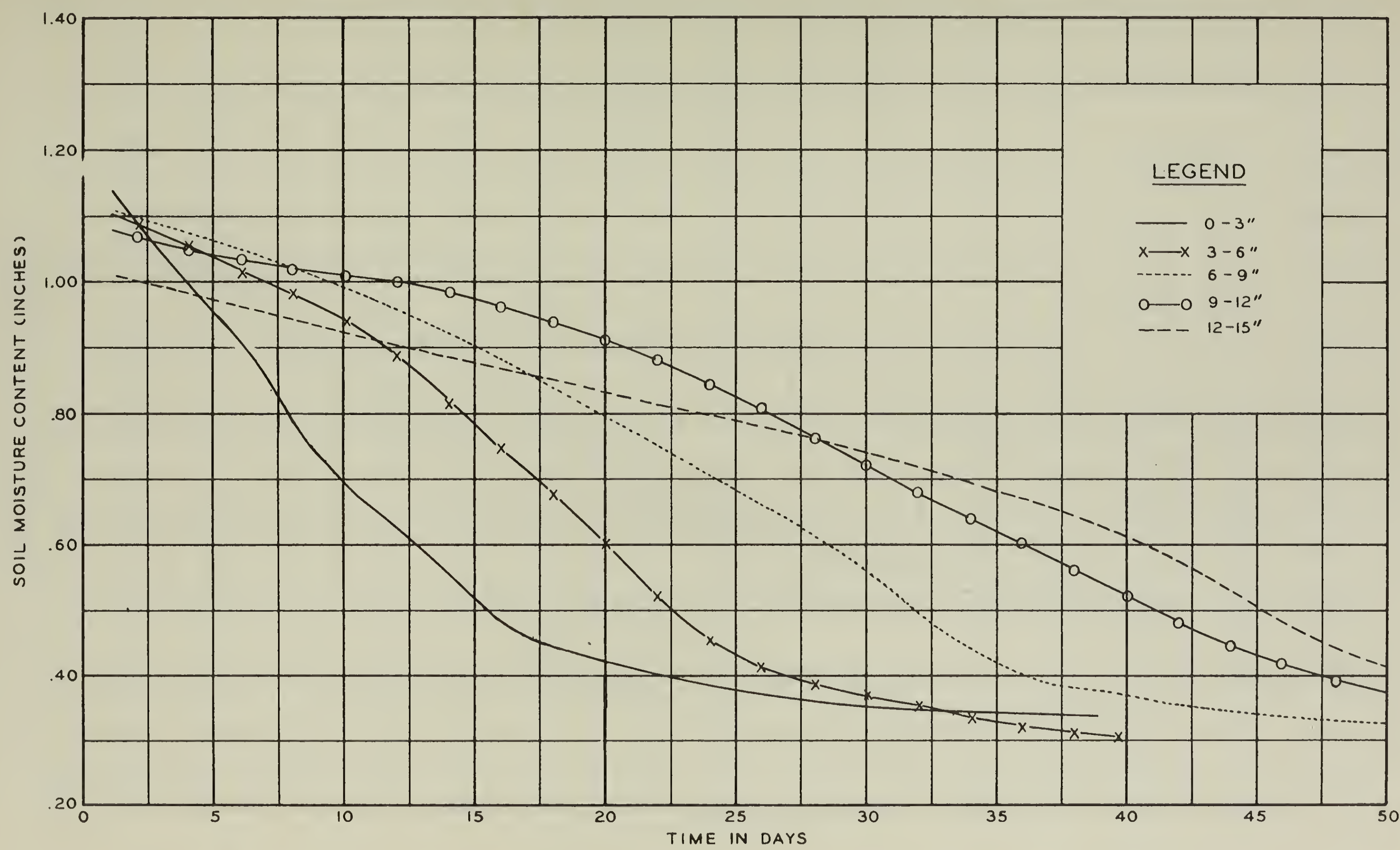


FIGURE 10- AVERAGE SOIL MOISTURE DEPLETION CURVES FOR PARK SITE

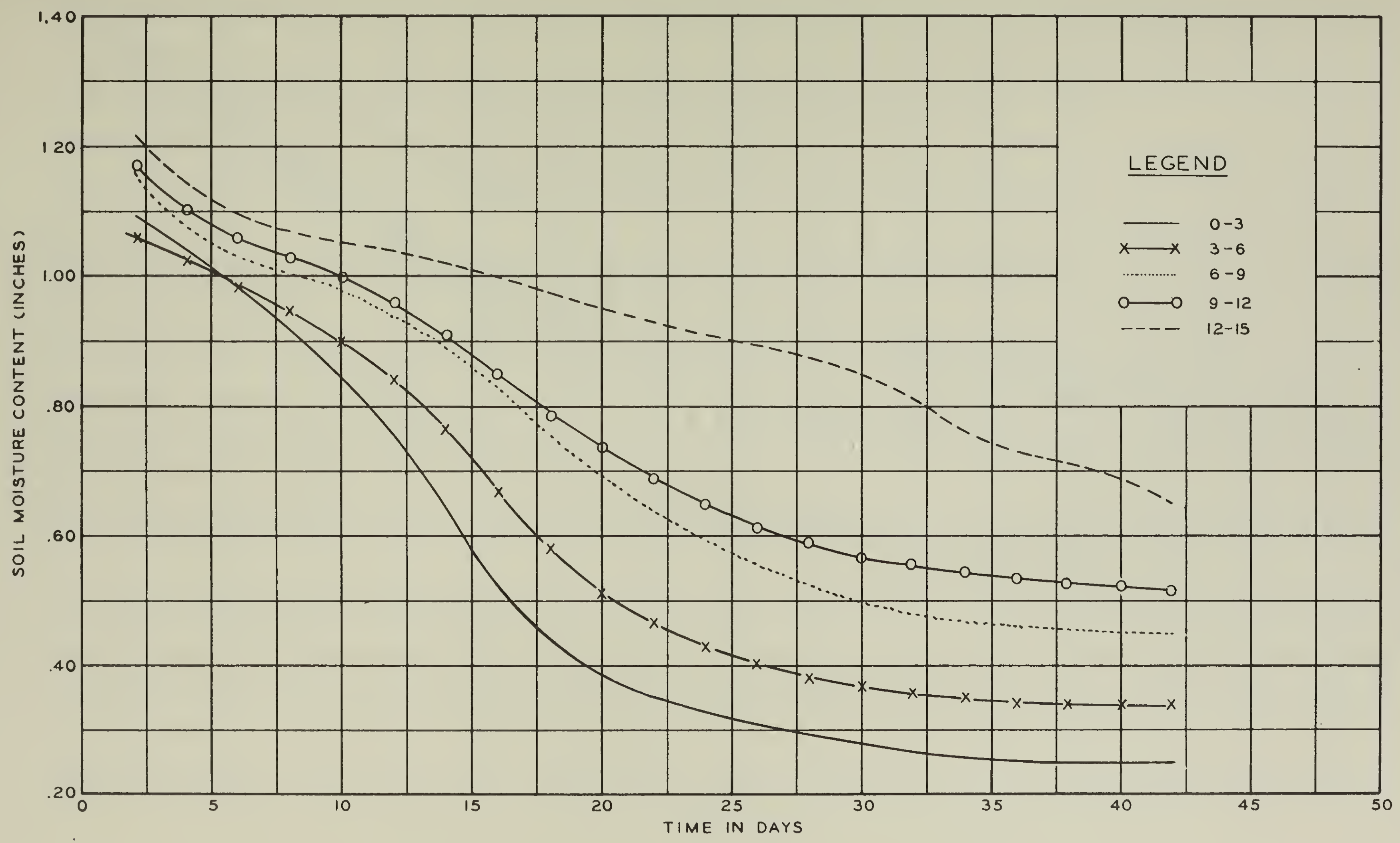


FIGURE 11- AVERAGE SOIL MOISTURE DEPLETION
CURVES FOR RIFLE SITE

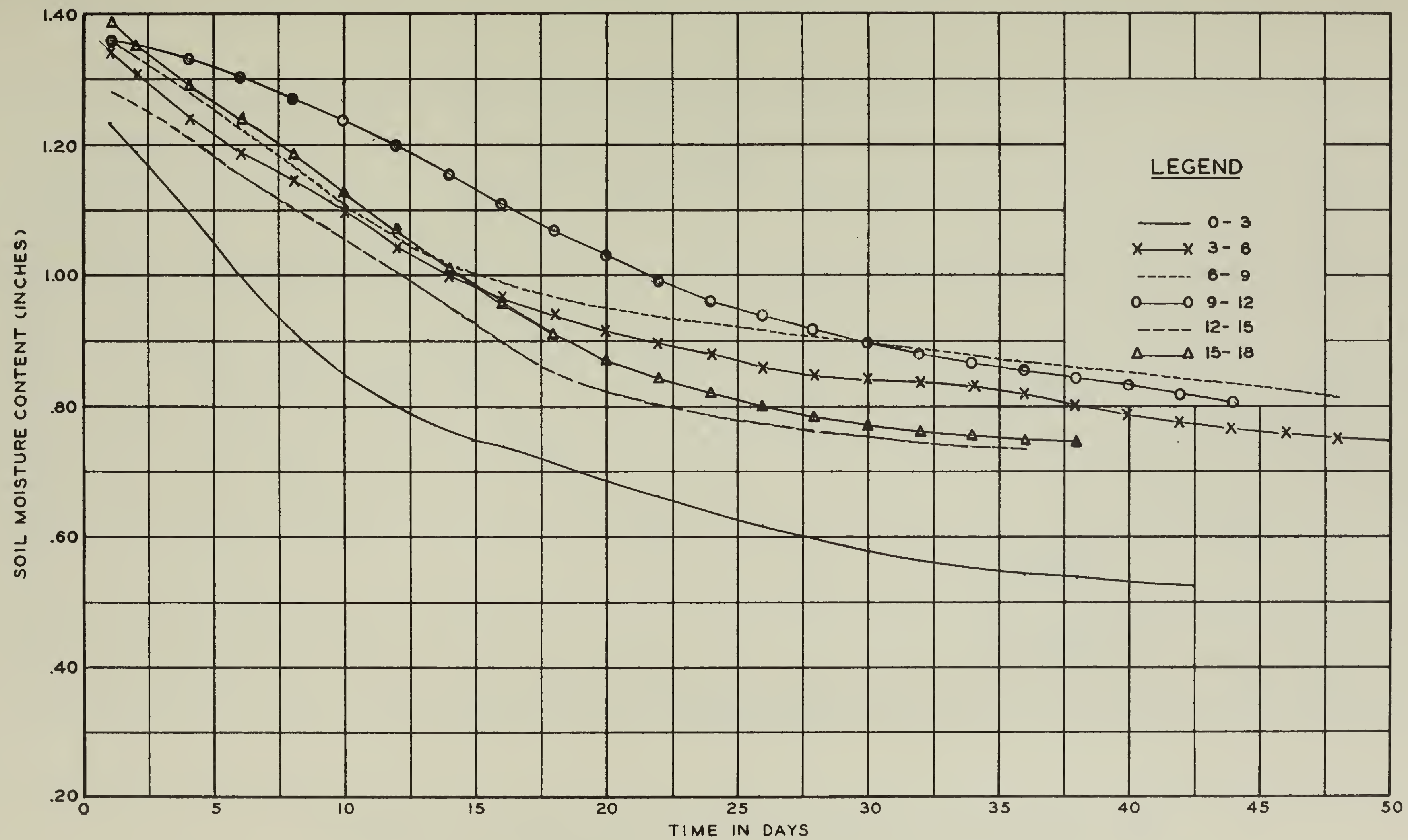


FIGURE 12. AVERAGE SOIL MOISTURE DEPLETION CURVES FOR MOUND SITE

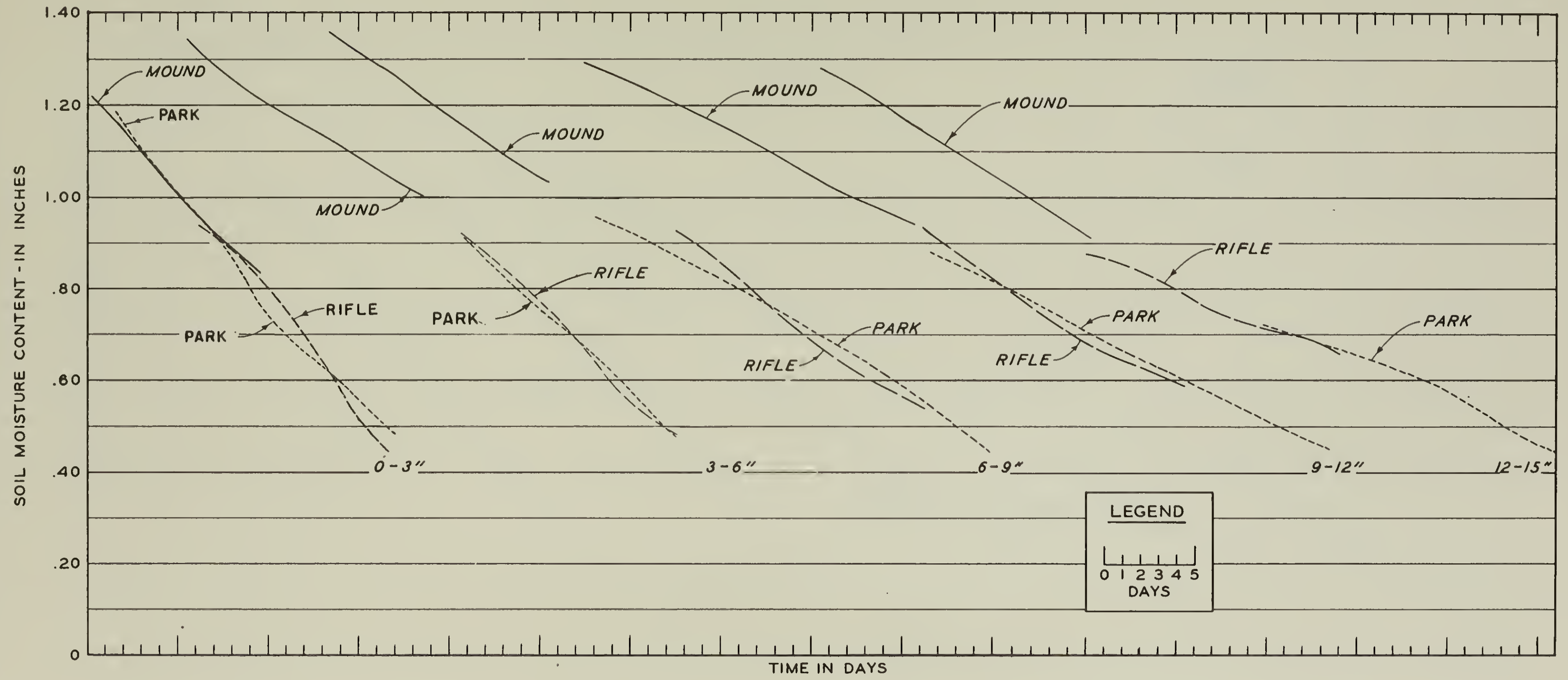


FIGURE 13. AVERAGE SOIL MOISTURE DEPLETION CURVES FOR MAXIMUM RATE OF WATER LOSS BY 3 INCH DEPTHS AT PARK, RIFLE RANGE AND MOUND, LA., SITES

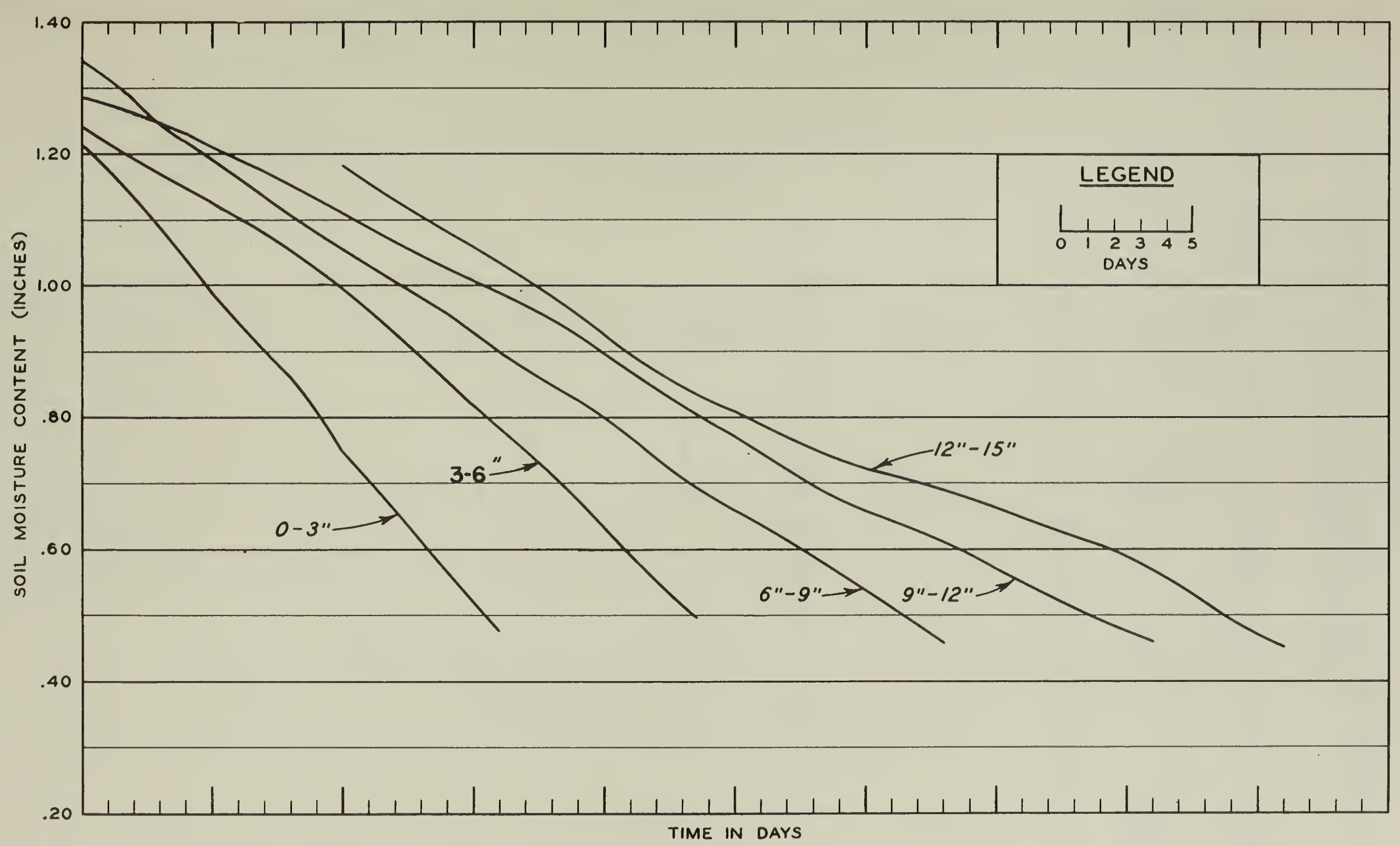


FIGURE 14. COMPOSITE OF AVERAGE MOISTURE DEPLETION CURVES FOR MAXIMUM RATE OF WATER LOSS BY 3 INCH DEPTHS - ALL SITES

Table 3

AVERAGE DAILY RATES OF MOISTURE LOSS IN INCHES FOR SIMILAR DEPLETION PERIODS

Soil Depth In.	Park No. of Days	Park Loss per Day In.	Rifle No. of Days	Rifle Loss per Day In.	Mound No. of Days	Mound Loss per Day In.
			Low Rates of Loss in Upper Moisture Range			
0-3	--	----	5	.028	--	----
3-6	10	.020	5	.020	--	----
6-9	11	.014	10	.022	--	----
9-12	13	.008	11	.021	5	.010
12-15	31	.009	25	.014	--	----
			Low Rates of Loss in Lower Moisture Range			
0-3	22	.006	23	.008	30	.010
3-6	17	.010	20	.006	32	.006
6-9	17	.006	14	.006	35	.006
9-12	10	.010	11	.004	18	.007
12-15	--	----	--	----	17	.006
			Maximum Rates of Moisture Loss			
0-3	16	.043	10	.049	9	.042
3-6	12	.038	13	.035	13	.026
6-9	22	.024	13	.030	12	.027
9-12	23	.020	15	.024	18	.019
12-15	21	.017	14	.016	17	.025

9- to 12-in. depth 8 days of intermediate rates are not included.

The low rates of loss at higher moisture contents were due to the slightly lower rate of extraction during the early spring. The low rates of moisture extraction at low moisture content are attributed to the increased moisture tension associated with soil drying. As the soil dries from field saturation to the air-dry state the forces holding moisture films increase from 0 to about 1000 atmospheres of tension. The tension is dependent on the thickness of moisture films around the soil particles. When the soil approaches wilting point (15 atmospheres) or higher tensions the moisture films are very thin and absorption by roots will be greatly reduced. Moisture movement in the soil to absorbing roots under these high tensions is negligible.

PREDICTION OF SOIL MOISTURE CONTENT

A comparison of predicted soil moisture content, determined by described accretion and depletion prediction methods, with actual soil moisture shows consistent agreement. Actual and predicted soil moisture accretions for each storm exceeding interception losses are listed by sites in Tables 4-6. Predictions are given for the 6- to 15-in. soil depth, the most critical zone from the standpoint of trafficability. As shown, the largest average deviation between predicted and actual values is 0.03 in. This should be well within the limits of tolerance for prediction.

The actual and predicted march of soil moisture during storm periods, in which there was 0.10 in. or more accretion in the 6- to 9-in. depth, is given for each site in Figures 15-17. On the rising side of the record,

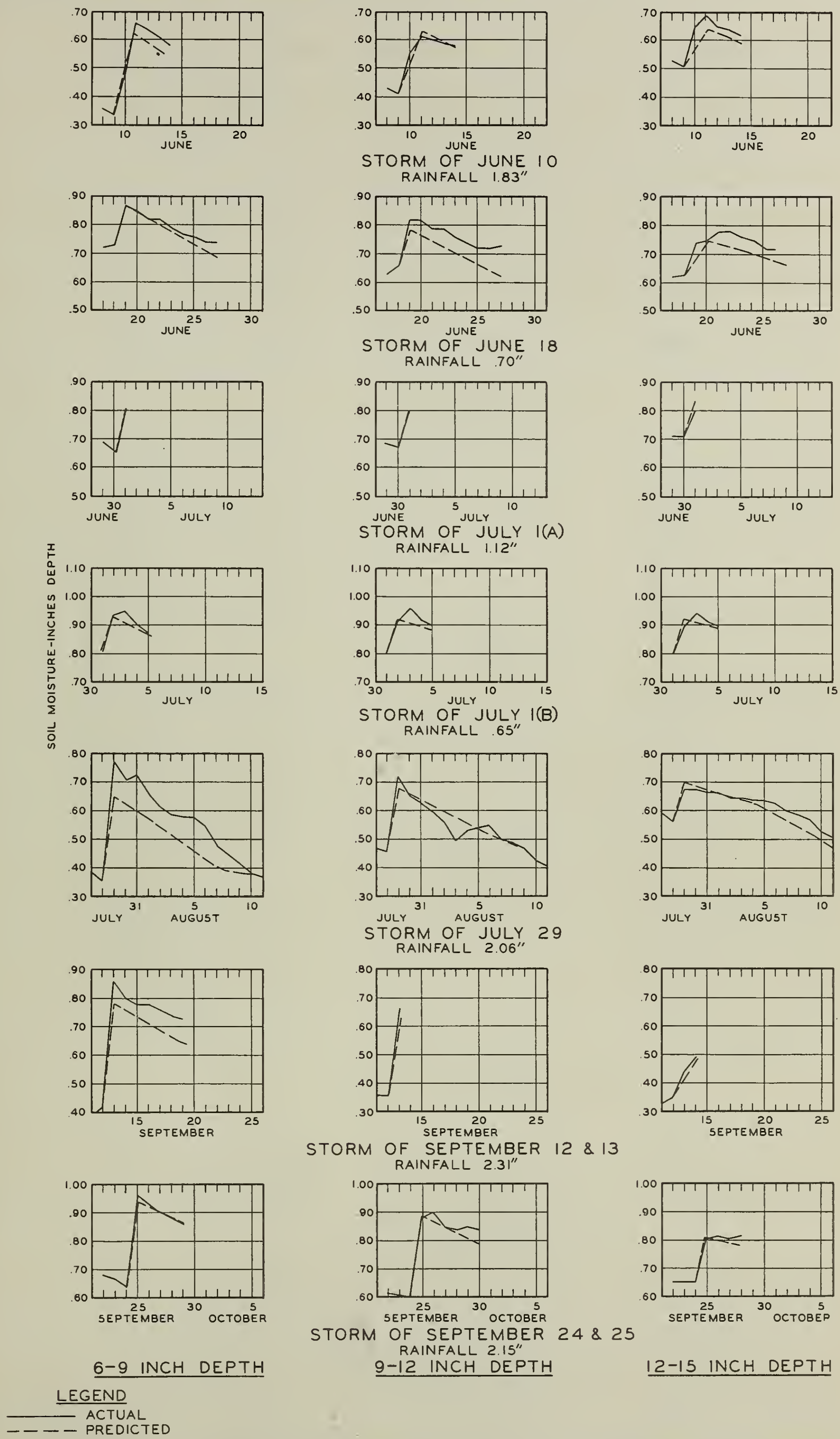


FIGURE 15. ACTUAL AND PREDICTED SOIL MOISTURE CONTENT FOR SEVEN STORM PERIODS AT PARK SITE

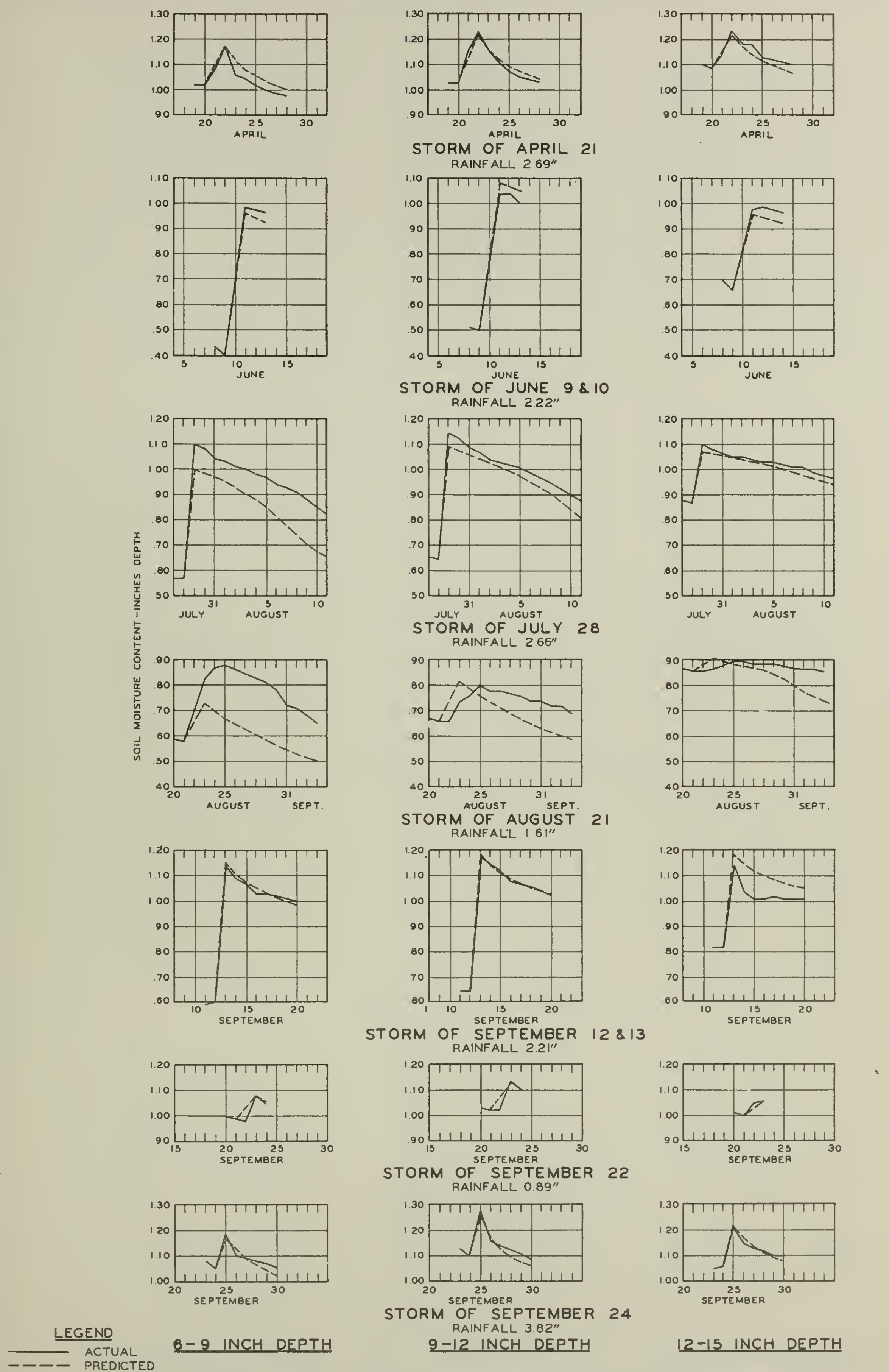


FIGURE 16. ACTUAL AND PREDICTED SOIL MOISTURE CONTENT FOR SEVEN STORM PERIODS AT RIFLE RANGE SITE

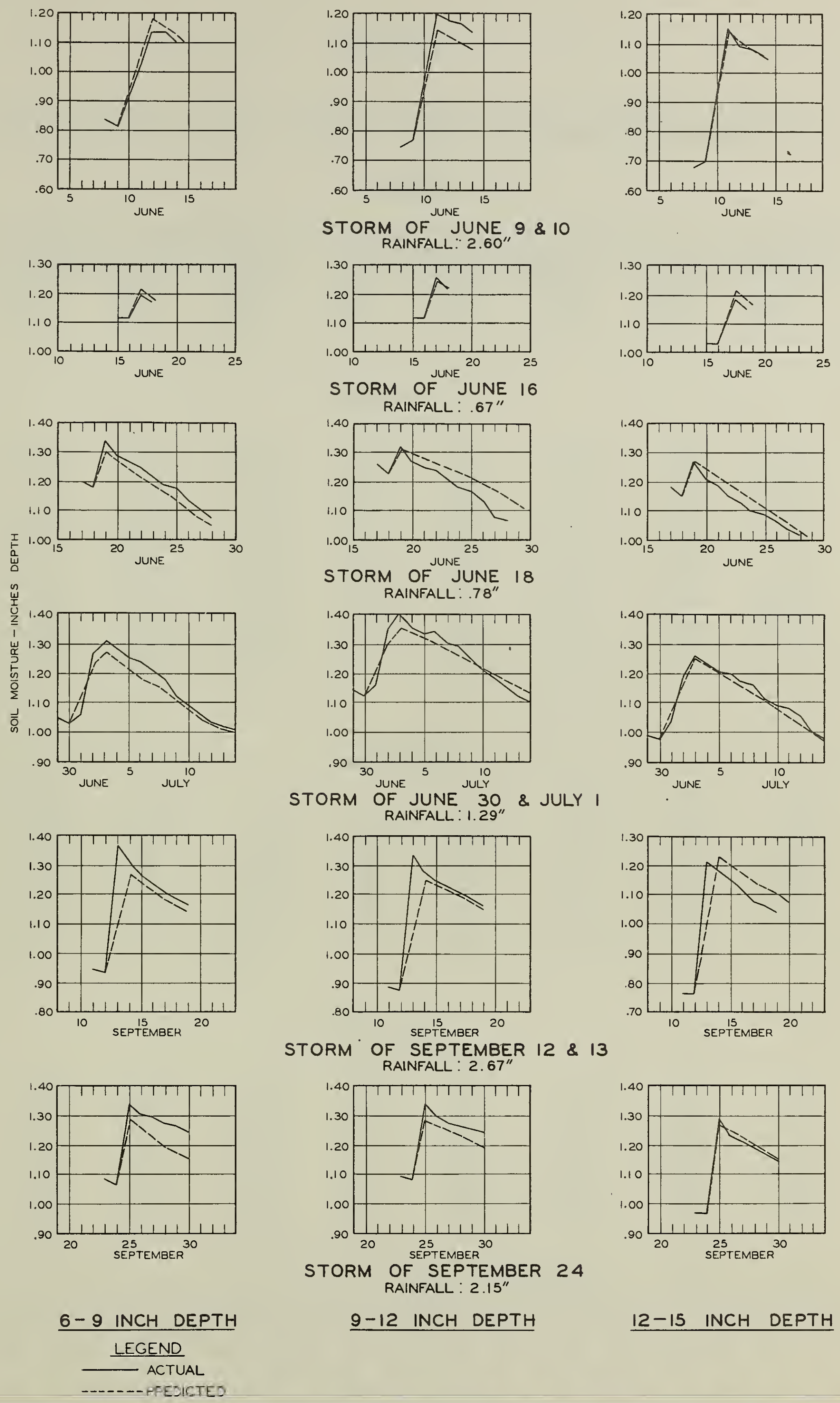


FIGURE 17. ACTUAL AND PREDICTED SOIL MOISTURE CONTENT FOR SIX STORM PERIODS AT MOUND SITE

Table 4

COMPARISON OF ACTUAL AND PREDICTED SOIL MOISTURE ACCRETION

PARK

Date of Storm	Actual Accretion 6-9 In.	Actual Accretion 9-12 In.	Actual Accretion 12-15 In.	Predicted Accretion 6-9 In.	Predicted Accretion 9-12 In.	Predicted Accretion 12-15 In.	Deviations 6-9 In.	Deviations 9-12 In.	Deviations 12-15 In.
				Class I					
5/9-10	0.00	0.00	0.00	.02	.01	0.00	.02	.01	0.00
6/14	.04	.01	0.00	.02	.01	0.00	.02	0.00	0.00
6/16	.10	.05	.02	.02	.01	0.00	.08	.04	.02
6/29	0.00	0.00	0.00	.02	.01	0.00	.02	.01	0.00
7/23	.01	0.00	0.00	.02	.01	0.00	.01	.01	0.00
8/21	.01	.01	.01	.02	.01	0.00	.01	0.00	.01
9/4	.01	.01	0.00	.02	.01	0.00	.01	0.00	0.00
9/9-10	0.00	0.00	0.00	.02	.01	0.00	.02	.01	0.00
				Class II					
4/19	.06	.05	.06	.09	.08	.09	.03	.03	.03
4/21(A)	.07	.02	.01	.08	.04	.04	.01	.02	.03
4/21(B)	.01	.02	.02	.01	.02	.02	0.00	0.00	0.00
7/2	.02	.04	.04	.02	.03	.04	0.00	.01	0.00
9/24-25	.32	.30	.15	.30	.31	.15	.02	.01	0.00
				Class III					
6/9-10	.31	.20	.18	.28	.22	.13	.03	.02	.05
6/18	.14	.16	.15	.13	.12	.12	.01	.04	.03
7/1(A)	.12	.13	.09	.12	.12	.12	0.00	.01	.03
7/1(B)	.12	.12	.10	.12	.12	.12	0.00	0.00	.02
7/29	.41	.26	.11	.29	.22	.13	.12	.04	.02
9/12-13	.44	.29	.12	.36	.27	.13	.08	.02	.01
					Mean Deviation		.03	.01	.01

Table 5

COMPARISON OF ACTUAL AND PREDICTED SOIL MOISTURE ACCRETION

RIFLE

Date of Storm	Actual Accretion 6-9 In.	Actual Accretion 9-12 In.	Actual Accretion 12-15 In.	Predicted Accretion 6-9 In.	Predicted Accretion 9-12 In.	Predicted Accretion 12-15 In.	Deviations 6-9 In.	Deviations 9-12 In.	Deviations 12-15 In.
				Class I					
4/19	.06	.05	.06	.05	.06	.04	.01	.01	.02
5/9-10	.10	.09	.02	.05	.06	.04	.05	.03	.02
6/14	.07	.10	.08	.05	.06	.04	.02	.04	.04
6/16	.05	.07	.08	.05	.06	.04	0.00	.01	.04
6/18	.02	.04	.03	.05	.06	.04	.03	.02	.01
6/28	.08	.10	.06	.05	.06	.04	.03	.04	.02
6/29	.07	.09	.05	.05	.06	.04	.02	.03	.01
6/30-7/1	.03	.04	.03	.05	.06	.04	.02	.02	.01
9/4	0.00	0.00	0.00	.05	.06	.04	.05	.06	.04
9/10	.01	0.00	0.00	.05	.06	.04	.04	.06	.04
				Class II					
4/21	.15	.19	.13	.15	.19	.13	0.00	0.00	0.00
7/1	.03	.06	.12	.09	.11	.12	.06	.05	0.00
9/12-13	.54	.52	.36	.55	.54	.37	.01	.02	.01
9/24	.14	.18	.16	.12	.16	.15	.02	.02	.01
				Class III					
6/9-10	.58	.55	.32	.57	.58	.30	.01	.03	.02
7/28	.53	.50	.23	.43	.44	.20	.10	.06	.03
8/21	.25	.08	.02	.15	.15	.05	.10	.07	.03
9/22	.10	.11	.07	.07	.11	.03	.03	0.00	.04
				Mean Deviation			.03	.03	.02

Table 6

COMPARISON OF ACTUAL AND PREDICTED SOIL MOISTURE ACCRETION

MOUND

Date of Storm	Actual Accretion 6-9 In.	9-12 In.	12-15 In.	Predicted Accretion 6-9 In.	9-12 In.	12-15 In.	Deviations 6-9 In.	9-12 In.	12-15 In.
				Class I					
4/19	.06	.04	0.00	.03	.03	.02	.03	.01	.02
5/10	.03	.02	0.00	.03	.03	.02	0.00	.01	.02
6/14	.01	0.00	0.00	.03	.03	.02	.02	.03	.02
7/23	.06	.05	.03	.03	.03	.02	.03	.02	.01
7/28	0.00	0.00	0.00	.03	.03	.02	.03	.03	.02
8/21	.08	.09	.12	.03	.03	.02	.05	.06	.10
9/4	0.00	0.00	0.00	.03	.03	.02	.03	.03	.02
9/10	.04	.04	.01	.03	.03	.02	.01	.01	.01
				Class II					
4/21(A)	0.00	0.00	0.00	0.00	0.00	.02	0.00	0.00	.02
4/21(B)	.02	0.00	.02	.01	0.00	.02	.01	0.00	0.00
6/18-19	.15	.09	.12	.12	.08	.13	.03	.01	.01
7/2	.04	.05	.06	.04	.05	.09	0.00	0.00	.03
9/12-13	.37	.40	.42	.33	.37	.47	.04	.03	.05
9/24	.27	.27	.32	.22	.20	.30	.05	.07	.02
				Class III					
6/9-10	.35	.42	.42	.36	.38	.43	.01	.04	.01
6/16	.09	.14	.15	.12	.12	.18	.03	.02	.03
6/30-7/1	.22	.20	.20	.18	.18	.21	.04	.02	.01
					Mean Deviation		.02	.02	.02

the predicted points represent soil-moisture accretion as predicted from the accretion analysis. Curves developed from the depletion analysis were used to predict the soil moisture record on the recession side. Note that variation between predicted and actual points is due primarily to the error in the accretion prediction. In almost all cases the slope of the actual and predicted depletions are very similar.

Application of Methods

The times when the prediction of soil moisture content may be necessary are analagous to the two methods of prediction previously described, accretion and depletion. If a prediction of soil moisture content immediately after a storm is required, the method of predicting soil moisture accretion would be used. A prediction of soil moisture content at any desired interval after a storm would involve use of the soil moisture curves previously established. Categorically, these two predictions may be expressed as simple questions: What is the effect of a storm of specified amount of rainfall on soil moisture content? How long will it take the soil to dry out to a specific moisture content? Of the two, the prediction of soil moisture content immediately after a storm is the more difficult.

To predict the effect of any storm in the future on the moisture content of soils similar to the ones described, two estimates are necessary:

(1) The amount of rainfall.

(2) The amount of available storage space.

Given these two values, a decision can be made as to the storm class in which the storm falls. If the rainfall-storage relation is such as to

produce either a Class I or Class II storm, the prediction is simply the single effect previously described. Under these conditions, no further computations would be necessary.

If, however, the storm fell into the Class III category, it would be necessary to calculate the amount of residual rainfall available for accretion at the 6- to 15-in. depth and allot this amount to the 3-in. soil depth increments according to the residual rainfall-available storage-accretion relationship.

Once the soil moisture content immediately after the storm is predicted, the prediction of moisture contents during subsequent drying intervals requires only reference to the soil moisture depletion curves. Entering these curves at the estimated soil moisture content, the soil moisture content at any subsequent drying time may be predicted by reading the values directly from the graph.

It should be pointed out that the prediction of soil moisture content immediately or several days after the storm can be no better than the values of predicted rainfall and storage on which it is based. Of the two, available storage prior to the storm can probably be estimated more accurately than predicted rainfall. Consideration of the errors inherent in the data on which the prediction is based makes it advisable to confine prediction methods to the simplest possible requirements both for data and analytical procedures.

Estimate of Available Storage

Prediction of available storage for soil moisture prior to any storm requires estimates of maximum and actual moisture contents. As noted, for

these soils, maximum moisture contents for depths below 3 in. are approximately equivalent to field capacity values determined in the laboratory. Estimation of the actual moisture content requires consideration of antecedent conditions. One condition, the simplest from the standpoint of estimating soil moisture content, is the relatively recent occurrence of a storm of sufficient size to saturate the upper 15 in. of the soil. With this condition, the moisture content for the day of prediction could be estimated with the aid of the depletion curves for each depth. In the summer months, however, such rains tend to be infrequent. For the period of record of this study, this situation occurred three times at Park, on April 21, July 2 and September 28.

A second condition which simplifies the estimate of actual moisture content is the occurrence of a long drying period prior to the storm. If it is of sufficient length, over 4 weeks for the soils in question, their moisture content will approximate the minimum moisture content and available storage can be computed from this value. These periods, too, are infrequent. At Park only 2 occurred, one in early June, the other in late August.

Between these two extremes, an extremely wet and a dry condition, is the more common situation in which one or more small storms have preceded the date on which an estimate of available storage is desired. Here, it would be necessary to go further back into the record to either the last extremely wet or dry condition, and determine the moisture conditions prior to intervening storms. The effect of the more recent smaller storms on soil moisture content could then be evaluated by a system of routing the water into and out of the soil, deriving both soil moisture and

available storage values.

Once the available storage value is estimated, the next step, as described above, is to compare storage with predicted rainfall, classify the storm, and on the basis of its class, predict the accretion and soil moisture content.

Soil Moisture Depletion

As noted before, the prediction of soil moisture content on the recession side of the soil moisture curve is much simpler than on the accretion side. With soil moisture depletion curves like the ones described, only one value, the initial soil moisture content, is necessary for prediction. With this value, subsequent daily soil moisture contents during a drying period can be read directly on the depletion curve.

The accuracy of this method is indicated in Figure 18 which compares actual daily moisture content with prediction values obtained from moisture depletion curves for two critical depths at Rifle. As indicated, the long-term predictions during a drought are subject to larger errors than any short-term forecast.

Another use of these curves is to derive the time required to reach a certain moisture content. Table 7 illustrates this aspect of prediction for the 6- to 9-in. depth at Park.

The accuracy of any short-term prediction is brought out in Figures 19 and 20. These data show the relation of today's moisture content with tomorrow's. The relation is strong for both depths at all sites.

Figures 19 and 20 are particularly significant because they show that the daily rate of loss for all three sites can be expressed by one

Table 7

NUMBER OF DAYS REQUIRED FOR DRYING BETWEEN SPECIFIED SOIL MOISTURE CONTENTS FOR PARK, 6- to 9-IN. DEPTH

Final Moisture Content	Number of Days							
	Initial Moisture Content (In.)							
	1.10	1.00	0.90	0.80	0.70	0.60	0.50	0.40
1.10								
1.00	8							
0.90	13	6						
0.80	18	10	5					
0.70	23	15	9	5				
0.60	27	19	14	9	4			
0.50	30	22	17	12	8	3		
0.40	34	27	21	16	12	8	4	

curve. The position that each site occupies on that curve depends on its moisture contents at field capacity and wilting point. Further study is necessary to determine the applicability of this curve to other soils. If it is applicable, prediction of soil moisture for other areas could be much simplified.

The inference in this relation is that soil moisture depletion is a physical process dependent on universal energy relations. As described in Appendix M, there appeared to be no correlation between any of the climatic factors measured and depletion rates. Instead, there was a strong indication that the rates depended on the amount of available moisture, the rates tending to be directly proportional to moisture content. The relation of moisture content to soil moisture tension when viewed in respect to soil moisture depletion may explain the simple relation described in Figures 19 and 20 (Appendices I and L).

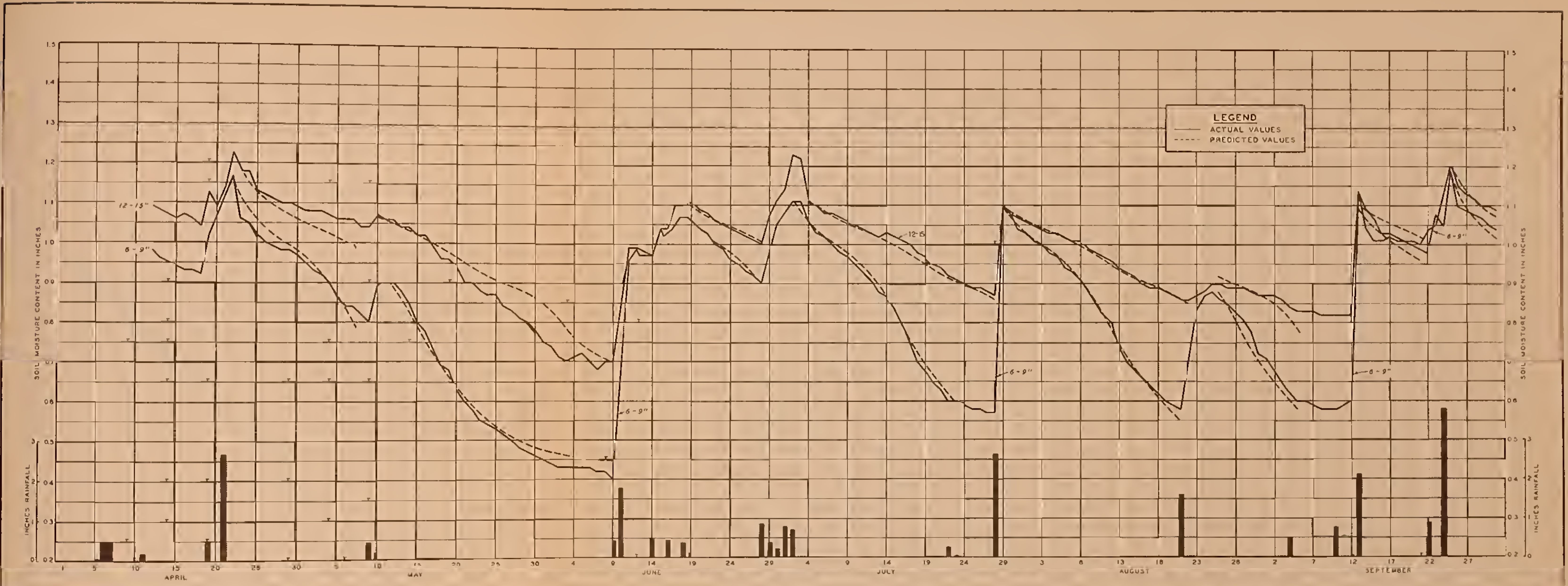


FIGURE 18. COMPARISON OF ACTUAL AND PREDICTED SOIL MOISTURE DEPLETION FOR THE 6-9 AND 12-15 INCH DEPTHS AT RIFLE RANGE SITE

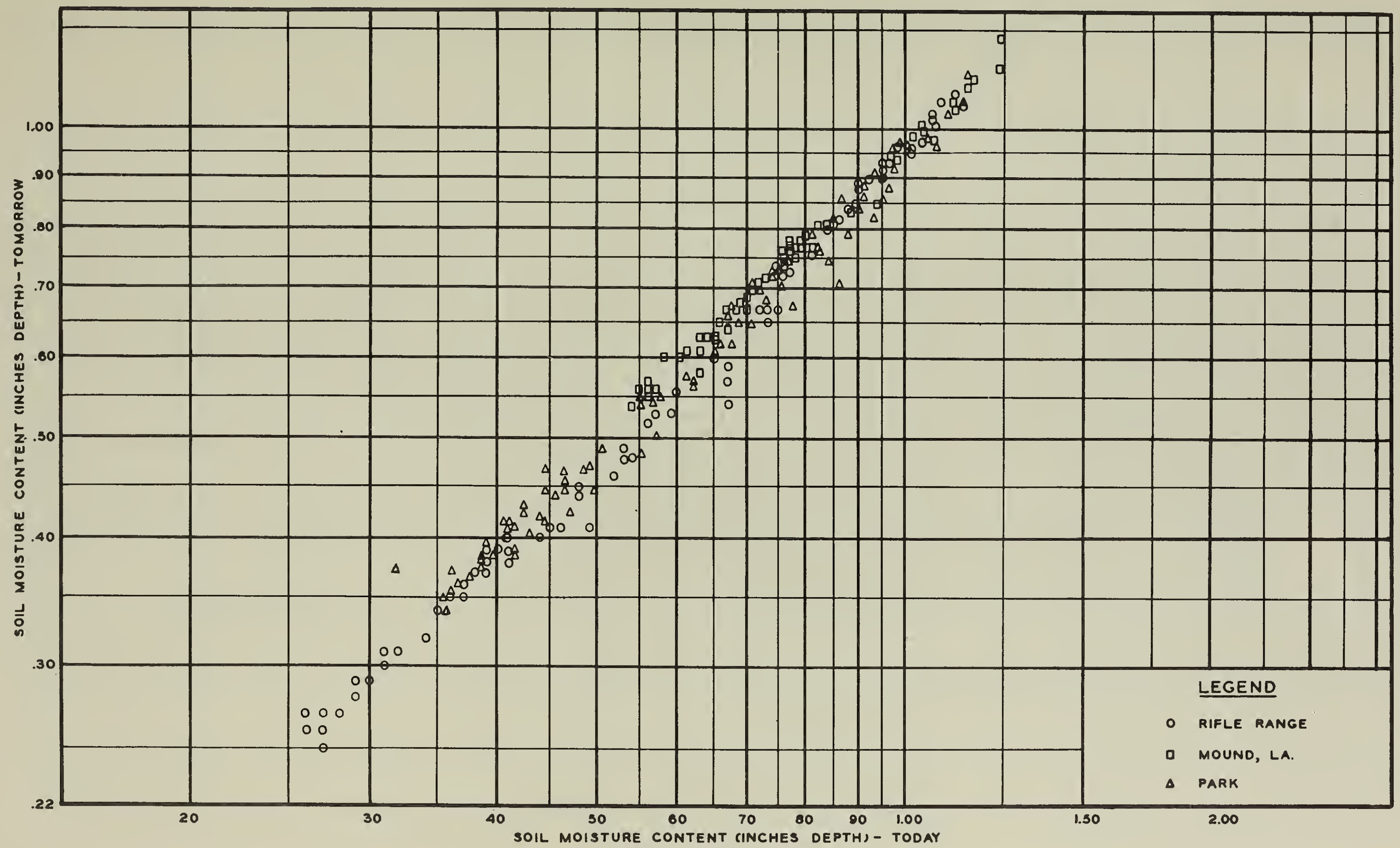


FIGURE 19. RELATION OF TODAY'S AND TOMORROW'S MOISTURE CONTENT FOR 0-3" DEPTH AT ALL SITES

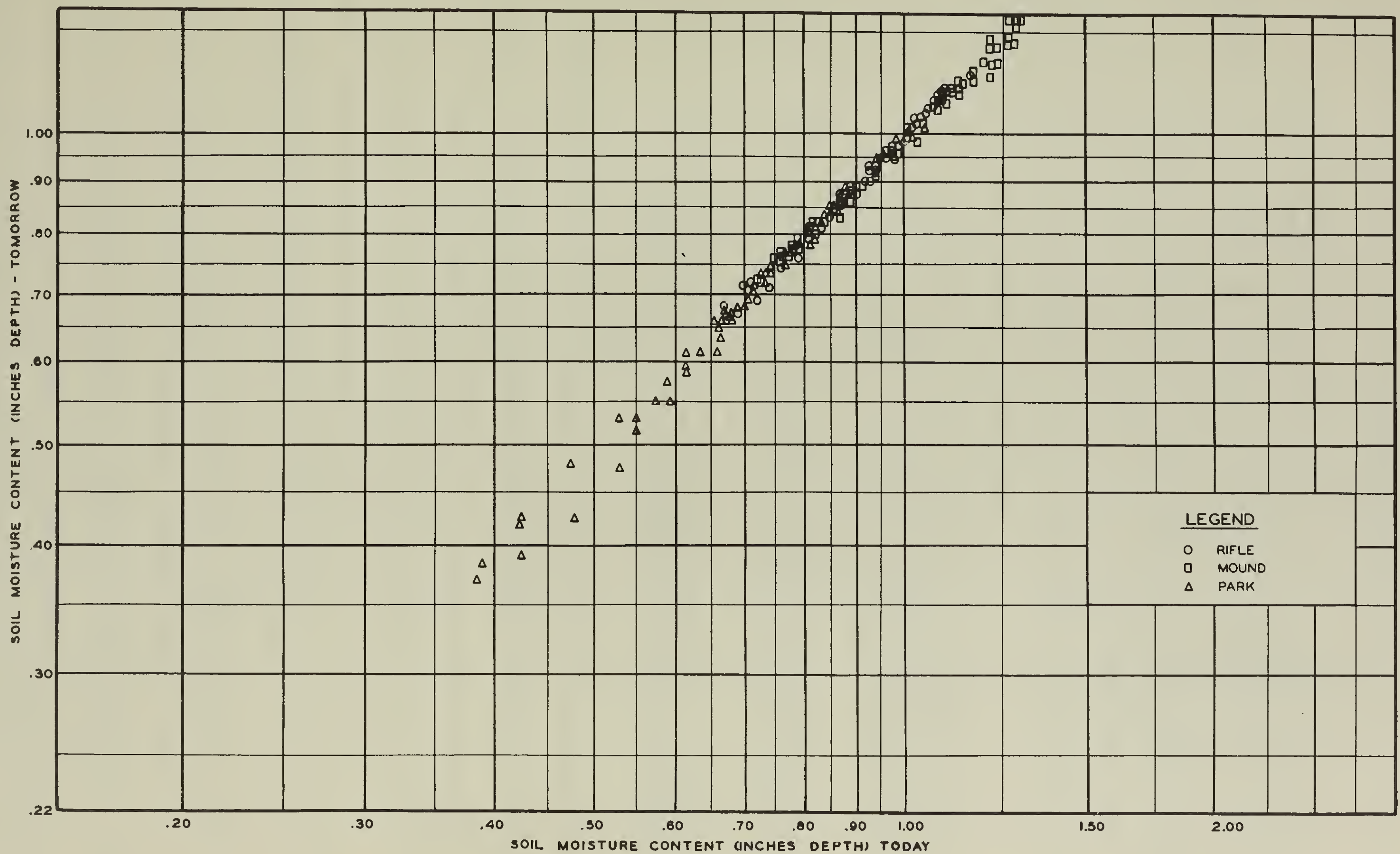


FIGURE 20. RELATION OF TODAY'S AND TOMORROW'S MOISTURE CONTENT FOR 12—15 INCH DEPTH AT ALL SITES

FUTURE PLANS

Future research on the prediction of soil moisture can best be discussed in relation to the two types of investigations that have been so far considered, the present pilot study, and the expanded program.

To complete the pilot study, work in the Vicksburg area should be continued until and completed by June 30, 1952. During this period the following objectives should be achieved:

(1) Collection of soil moisture data should continued to April 1, 1952 to provide information on soil moisture contents and rates of accretion and depletion during fall, winter and spring seasons.

(2) Completion of a final report on the pilot study by June 30, 1952, covering the period April 1, 1951 - April 1, 1952.

(3) Preparation of a work plan to cover investigations of other areas, if the project is to be continued beyond June 30, 1952.

Before completion of the pilot study several important and promising phases of prediction should be given further attention. For instance, the use of soil moisture tension as a universal value in predicting moisture content and trafficability should be given more study. Detailed studies now in progress for the determination of factors responsible for the resistance-moisture relations in the fiberglas units should be continued in order to provide accurate and rapid means of calibrating these units for future investigations. These include special studies involving the relation of moisture tension to soil separates, fiberglas, and natural soil. A third study is a comparison of the Bouyoucos nylon and plaster of Paris units and the Colman unit in regard to sensitivity and accuracy of their soil moisture records.

If at all possible, some attention should be paid to recent developments in soil sampling devices and soil moisture instruments. For instance, the feasibility of measuring soil moisture and density by neutron and gamma-ray scattering (1) should be studied. The great amount of information on soil moisture and density for the prediction sites would make the Vicksburg area an ideal place for such a test. Attention should also be paid to developing a recording instrument with the Colman meter, a device which could materially facilitate collection of soil moisture data.

Expanded Program

In the past, consideration of the expansion of the soil moisture prediction study to other areas has always involved the use of "infiltrometer crews" to conduct the investigation on each area selected for study. Based on findings and experience obtained in the pilot study, this approach is no longer considered necessary. Instead, it is suggested that the future program be based on installations that can be supervised by one technician in each area for which information is desired.

With this approach, the individual assigned to the area, preferably a man trained on the Vicksburg project, would be responsible for the collection of soil moisture and climatic data similar to that obtained during the pilot study. If Forest Service research centers could be used as headquarters, field and laboratory equipment, and office space could no doubt be made available. Perhaps more important, the accumulated knowledge of soils and vegetation possessed by Forest Service personnel at

each center would assist greatly in the conduct of the study.

The basic procedure on each area would be the installation and calibration of Colman units according to procedures developed during the pilot study. Pertinent climatic, soil and vegetation factors would be studied and measured, again, according to procedures used at Vicksburg. Soil moisture plots could be sprinkled if necessary to increase the number of accretion and depletion periods. Development of the march of soil moisture could be facilitated by using the procedures described in this report.

At some of the western research centers, where, due to large differences in elevation several distinct great soil groups are found within a distance of a few miles, it may be desirable to install Colman units in each of the soil groups represented.

The expanded program would necessarily be administered from the Waterways Experiment Station. A central soils laboratory at the Station should be set up to handle necessary physical and chemical soil analyses.

If costs of such a program were limited to the amounts spent on the pilot study, it is estimated that investigation could be started in 3 to 5 areas. Equipment purchased for the pilot study could be made available for the expanded studies.

LITERATURE CITED

1. Belcher, D. J., Cuykendall, T. R. and Sack, H. S.
1950. The measurement of soil moisture and density by neutron and gamma-ray scattering. Technical Development Report No. 127, Civil Aeronautics Administration.

2. Colman, E. A.
1946. The place of electrical soil-moisture meters in hydrologic research. Amer. Geophys. Union Trans. 27:847-853

3. Corps of Engineers, U. S. Army
1950. Forecasting trafficability of soils. Report No. 1. Waterways Experiment Station, Vicksburg, Mississippi.

4. Croft, A. R.
1950. A water cost of runoff control. Jour. of Soil and Water Conserv. 5(1): 13-15, illus.

5. Dortignac, E. J
1951. Design and operation of Rocky Mountain infiltrometer. Station Paper No. 5, Rocky Mountain Forest and Range Exp. Sta., Fort Collins, Colo.

6. Hoover, M. D.
1950 Hydrologic characteristics of South Carolina Piedmont forest soils. Soil Sci. Soc. of Amer. Proc. 14:353-358, illus.

7. Kramer, Paul J.
1949. Plant and soil water relationships. New York.

8. Lassen, Leon, H. W. Lull and Bernard Frank
1951. Some fundamental plant-soil-water relations in watershed management. U. S. Dept. of Agric., Forest Service

9. Rowe, P. B. and E. A. Colman
1951 or 1952. Disposition of rainfall in two mountain areas of California. To be published as a Tech. Bul., U. S. Dept. Agric.

ACKNOWLEDGMENTS

The investigations reported herein were conducted for the Trafficability Section, Flexible Pavement Branch, Soils Division, Waterways Experiment Station. Engineers concerned with the initiation, progress and results of this study are: Messrs. W. J. Turnbull, C. R. Foster, S. J. Knight, and A. A. Rula.

From March 1 to July 1 the study was conducted under the general direction of Mr. E. N. Munns, Chief, Division of Forest Influences, Forest Service. After July 1 the project was under the direction of Mr. Bernard Frank, Acting Chief, Division of Forest Influences.

Forest Service personnel assigned to the project and actively engaged in the field work and analyses are listed:

Entire study period

E. J. Dortignac, In Charge
Kenneth G. Reinhart
Charles A. Carlson
Basil D. Doss
Norman K. Garber
James C. Holland
Joseph J. B. Kennedy
Richard E. Larson
Edgar H. Palpant
John L. Thames

March to July

J. S. Horton
J. A. Rushing
R. Stumpf

July to present

Howard W. Lull
Edwin R. Murphy

All personnel on the project since July contributed materially to the preparation of these reports. In addition, many Forest Service personnel contributed to the over-all study directly and indirectly. Mr.

Leon Lassen acted in the capacity of technical advisor throughout the study. M. D. Hoover and E. A. Colman served as consultants on several phases of the work.

Mr. Carl Englehorn, Soil Conservation Service, was loaned to the project from April to July.

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FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE

THE DEVELOPMENT OF METHODS FOR PREDICTING SOIL MOISTURE CONTENT

PROGRESS REPORT II

CONDUCTED FOR

WATERWAYS EXPERIMENT STATION
CORPS OF ENGINEERS, U. S. ARMY
VICKSBURG, MISSISSIPPI

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ARMY-MRC VICKSBURG MISS.

JULY 1952

PREFACE

This report covers one phase of the over-all study to determine the relationship between trafficability of soils and the mobility of military vehicles. This phase is concerned solely with the development of methods for predicting soil moisture content for specific soils, vegetation, and weather conditions. The ultimate objective is to enable military planners to forecast trafficability of soil in strategic areas without resorting to physical tests.

The Waterways Experiment Station, in February 1951, requested the Forest Service, U. S. Department of Agriculture to assist in this phase. By mutual agreement, the first Forest Service studies were conducted on three sites near Vicksburg, Mississippi, which the Waterways Experiment Station was using for trafficability investigations.

It was further agreed that the preliminary investigations would serve as a pilot study for developing methods for predicting soil moisture content. On the basis of the findings the Waterways Experiment Station would decide on the practicability of methods and determine the feasibility of extending this study to other areas.

Results from the first six months of study, April 1 through September 30, 1951 were reported in Progress Report I. This report, Progress Report II, describes results obtained in the subsequent six months, October 1, 1951 through March 31, 1952. The investigations reported herein are a continuation of the work covered in Progress Report I, which was under the leadership of E. J. Dortignac, U. S. Forest Service.

Personnel of the Waterways Experiment Station concerned with the

initiation, progress and results of this study are: Messrs. W. J. Turnbull, C. R. Foster, S. J. Knight, and A. A. Rula.

From October 1, to January 10 this study was conducted under the general direction of Mr. Bernard Frank, Acting Chief and Dr. H. G. Wilm, Chief, Division of Forest Influences, Washington office, Forest Service. On January 10, general direction of the Project was transferred to Mr. H. L. Mitchell, Director, Southern Forest Experiment Station, New Orleans, Louisiana.

Forest Service personnel assigned to the Project and actively engaged in the field work, and analysis of data were:

Howard W. Lull, In Charge	James C. Holland
Kenneth G. Reinhart	Ralph Moyle
Charles A. Carlson	Edwin R. Murphy
Basin D. Doss	Edgar H. Palpant
Norman K. Garber	Robert E. Taylor
George B. Herring	John Thames

Robert Tobiaski

Mr. Leon Lassen was the technical advisor throughout the study.

All personnel of the Project Staff participated in the preparation of this report. Though the separate sections were assigned to and prepared by various individuals, the results represent the collective work and judgment of the entire group. General responsibility for preparation of the various sections was as follows:

Introduction	Lull
Climatic Summary	Doss
Vegetation Summary	Thames

Soil Classification	Carlson
Soil Moisture Accretion from Rainfall	Carlson - Taylor
Effect of Water Table Levels on Soil Moisture Content	Reinhart
Soil Moisture Depletion	Holland - Moyle
Prediction of Summer Soil Moisture Depletion	Lull
Long-term Predictions of Soil Moisture Content	Reinhart - Carlson
Review of Special Studies	Lull - Carlson
Future Plans	Lull

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CONTENTS (Continued)

SUMMARY

In Progress Report I, methods of predicting soil moisture content were developed for three sites in the Vicksburg area: Park, Rifle and Mound. The period covered therein was from April 1 to October 1, 1951, designated the "summer" season. Prediction methods for the period October 1 to April 1, the "winter" season, have since been developed for these same sites and are presented in this report.

Basic data from which to develop prediction methods consisted of a daily record of soil moisture from October 1, 1951 to April 1, 1952 for each site, a water table record for Rifle and Mound, and concurrent data on rainfall, air and soil temperatures, humidity and wind movement. Condition of vegetation was checked periodically. With cooperation of the ~~Soils~~ Soil Survey, soils at each prediction site were classified.

As in the summer season, soil moisture accretion during winter was found to be dependent on storm size and available storage; consequently storms were grouped into two size categories. Class I-W included all storms with rainfall less than the available storage in the 0- to 12-inch soil depth. Class II included all storms with rainfall equal to or greater than available storage in the 0- to 12-inch depth. These classes describe the winter condition of low available storage in which a storm either very slightly wets (Class I-W) or fully satisfies (Class II) the available storage in the 6- to 12-inch depth.

In winter, due to the sparse vegetation and reduced evaporation, rainfall interception was negligible. Consequently, it was not considered in the prediction of soil moisture content as it had been for summer

THE DEVELOPMENT OF METHODS FOR PREDICTING SOIL MOISTURE CONTENT

PROGRESS REPORT II

INTRODUCTION

This is the second progress report on investigations being conducted by the Forest Service for the Waterways Experiment Station, Vicksburg, Mississippi. The purpose of the investigations is to develop methods for predicting soil moisture content.

This report covers the period from October 1, 1951 to April 1, 1952. This period is generally characterized by low temperatures, frequent rainfalls, and vegetal dormancy, factors which separately and in combination influence the soil moisture content.

The same prediction sites and soil moisture and climatic installations were used in this period as during the first six months of the study described in the first progress report (hereafter referred to as Progress Report I). For ready reference, the pertinent features of each prediction site are summarized in Table 1.

This report, as originally planned, was to cover the entire year's record. However, the results obtained during the second six months of study and the conditions that produced them were found sufficiently distinctive to warrant their recording in a separate report.

Factors Affecting Soil Moisture Content Under Winter Conditions

The factors affecting soil moisture content under winter conditions are most easily described in light of the summer conditions and results reported in Progress Report I. The winter conditions that prevailed for

Table 1

SITE CHARACTERISTICS AND INSTRUMENTATION OF THE PREDICTION AREAS

	Park Site	Rifle Site	Mound Site
Topography	Upland moderately sloping	Level to stream bottomland gently sloping	Level river bottomland to gently sloping
Soil type	Loring silt loam Grenada silt loam	Collins silt loam	Commerce clay
Vegetation (Dominant species)	Wild barley Vetch Dallis grass	Coneflower Wild barley Johnson grass	Aster Vetch White clover Wild pea
Instrumentation			
Number of:			
Tiers	4	4	4
Colman units	36	34	38
Tensiometers		2	2
Wells		5	4
Stream staff gages		1	1
Weather station			
Number of:			
Standard rain gages	1	1	1
Recording rain gages	2	1	1
Hygrothermographs	1	1	1
Anemometers		3	3

the greater part of the period covered in this report were such as to produce an entirely different soil moisture regime than that of the summer. Environmental factors affecting soil moisture accretion and depletion were either entirely different, or, if similar, differed in magnitude. Rainfall,

for instance, occurred more frequently than in the summer. Rainfall intensities were considerably lower and storm periods were longer, the rainy season typical of this area. Consequently, the soil was wet more often and for longer periods of time.

Accentuating and adding to this condition were the concurrent low rates of evapo-transpiration. Vegetation was dormant because of a succession of frost and low temperatures. These low temperatures effectively reduced evaporation, despite the prevailing high moisture content and considerable wind movement.

A third factor serving to maintain soil wetness was the rise in water tables to such a level that they affected soil moisture content at the prediction depths; this rise resulted from the combination of frequent rainfall and low rates of evapo-transpiration. In a sense, the rise in the water table constituted a second water source for soil moisture accretion.

The resultant of these factors was to produce, in general, a soil moisture regime following a regular pattern. At prediction depths the low storage opportunity of the wet soils was satisfied by most of the rainfalls. Soil moisture depletion between rainfalls was characterized first by a relatively rapid depletion as the water above field capacity drained out of the soil, and then a very low rate of depletion, reflecting the low evaporation rates.

When water table was a factor, this regime was modified by its effect both on accretion and depletion. At high levels, it tended to hold up and maintain high moisture contents. As the levels receded, the effect was to steepen the depletion curves. However, because of its frequency,

rainfall had a greater effect on accretion than did the water table.

At the beginning and end of the six-month period there were intervals when the soil moisture regime was intermediate between the summer and winter patterns, being affected by high available storage in the fall before the profile was saturated and by the early spring development of vegetation.

CLIMATE

This summary covers the period from October 1, 1951 to April 1, 1952, for the three prediction sites, Park, Rifle and Mound. The records taken at these sites are compared with each other and whenever possible with the Vicksburg Weather Bureau record during the 6-month period and also with the average values of the long-time Vicksburg record.

The type, number, and location of weather instruments for this period were the same as for the summer period as described in Progress Report I.

Precipitation

Table 2 gives the monthly precipitation at each prediction site, at the Vicksburg Weather Bureau and also the 80-year average at Vicksburg. The total precipitation for the period was considerably less than the 80-year average. The average total precipitation for the three prediction sites was 21.12 in. as compared to 28.14 in. for the long-time average. Only two months of the 6-month period, December and February, had rainfall above average. January and March had considerably less than the average. The total precipitation for October and November at all prediction sites was less than half the 80-year average; in October, Park received only 0.98 in. rain as compared with 2.59 in. for the long-time Vicksburg average. The average precipitation for all sites for the past 12-month period was 44.69 in. as compared to 51.71 in. for the long-time average.

Table 3 gives the dates and amounts of rainfall at each prediction

Table 2

PRECIPITATION BY MONTHS

Month	October 1, 1951 to April 1, 1952 Park	Rifle	Mound	Vicksburg	80-Year Record at Vicksburg Avg	Wettest	Driest
				Inches			
October	0.98	1.22	1.03	0.96	2.59	17.26	Trace
November	1.70	1.80	1.95	1.74	4.15	16.28	Trace
December	6.55	5.86	6.38	6.37	5.26	13.77	0.99
January	3.07	3.58	3.16	3.08	3.32	13.83	0.37
February	5.39	5.17	4.03	5.09	4.87	11.45	0.44
March	3.72	3.64	4.10	3.89	5.95	14.52	0.53
Total for Period	21.41	21.27	20.65	21.13	28.14		

Table 3

DATES AND AMOUNTS OF PRECIPITATION AT EACH SITE

Date	Park Amount (In.)	Park Cumulative (In.)	Rifle Amount (In.)	Rifle Cumulative (In.)	Mound Amount (In.)	Mound Cumulative (In.)
Oct 7	-	--	0.04	0.04	0.06	0.06
22	-	--	-	-	0.10	0.16
23	0.69	0.69	0.84	0.88	0.20	0.36
27	-	-	-	-	0.11	0.47
29	-	-	-	-	0.01	0.48
30	0.01	0.70	0.01	0.89	-	-
31	0.28	0.98	0.33	1.22	0.55	1.03
Total		0.98		1.22		1.03
Nov. 1	0.15	0.15	0.12	0.12	0.11	0.11
3	0.01	0.16	0.03	0.15	0.06	0.17
5	-	-	-	-	0.02	0.19

(Continued on next page)

Table 3 (Cont'd)

Date	Park Amount (In.)	Park Cumulative (In.)	Rifle Amount (In.)	Rifle Cumulative (In.)	Mound Amount (In.)	Mound Cumulative (In.)
Nov. 6	0.36	0.52	0.47	0.62	0.27	0.46
10	0.12	0.64	0.16	0.78	0.14	0.60
11	0.02	0.66	-	-	-	-
12	0.05	0.07	0.01	0.79	0.02	0.62
14	0.33	1.04	0.45	1.24	0.63	1.25
15	0.06	1.10	0.05	1.29	0.08	1.33
26	0.06	1.16	0.02	1.31	0.03	1.36
27	0.54	1.70	0.49	1.80	0.59	1.95
Total		1.70		1.80		1.95
Dec. 3	0.75	0.75	0.73	0.73	0.89	0.89
4-5	0.40	1.15	0.32	1.05	0.29	1.18
7	1.28	2.43	1.05	2.10	1.40	2.58
8-9	1.76	4.19	1.74	3.84	2.06	4.64
10	0.03	4.22	0.02	3.86	0.03	4.67
14	0.92	5.14	8.81	4.67	0.52	5.19
17-18	0.33	5.47	0.29	4.96	0.30	5.49
19-20	1.02	6.49	0.78	5.74	0.79	6.28
25	0.06	6.55	0.12	5.86	0.10	6.38
Total		6.55		5.86		6.38
Jan. 4	0.74	0.74	0.82	0.82	0.63	0.63
9	0.16	0.90	0.23	1.05	0.17	0.80
15	0.08	0.98	0.03	1.08	0.12	0.92
18	0.02	1.00	0.05	1.13	0.05	0.97
20	0.26	1.26	0.38	1.51	0.32	1.29
27	1.81	3.07	2.07	3.58	1.87	3.16
Total		3.07		3.58		3.16
Feb. 1	1.17	1.17	1.12	1.12	1.13	1.13
4	0.21	1.38	0.19	1.31	0.16	1.29
11	-	-	0.03	1.34	0.03	1.32
12	0.45	1.83	0.47	1.81	0.57	1.89
13	0.15	1.98	-	-	0.13	2.02
14	0.10	2.08	0.07	1.88	0.05	2.07
15	1.65	3.73	0.45	2.33	0.65	2.72
16	-	-	1.30	3.63	-	-
20	0.30	4.03	0.35	3.98	0.32	3.04
22	0.95	4.98	0.70	4.68	0.57	3.61
23	0.05	5.03	0.08	4.76	0.03	3.64
25	0.25	5.28	0.25	5.01	0.25	3.89
26	0.11	5.39	0.16	5.17	0.14	4.03
Total		5.39		5.17		4.03

(Continued on next page)

Table 3 (Cont'd)

Date	Park Amount (In.)	Park Cumulative (In.)	Rifle Amount (In.)	Rifle Cumulative (In.)	Mound Amount (In.)	Mound Cumulative (In.)
Mar. 3	0.68	0.68	0.68	0.68	0.60	0.60
9	0.11	0.79	0.12	0.80	0.08	0.68
10	1.64	2.43	1.20	2.00	1.76	2.44
18	0.75	3.18	0.77	2.77	0.94	3.38
22	0.45	3.63	0.77	3.54	0.59	3.97
30	0.05	3.68	0.05	3.59	0.06	4.03
31	0.04	3.72	0.05	3.64	0.07	4.10
Total		3.72		3.64		4.10

site. Although there was less rainfall for the winter period than for the summer period, rain occurred more often. During the winter period, rainfall occurred on 51 days at Park, 53 days at Rifle and 55 days at Mound, or roughly, rain occurred one day out of three. During the summer period rainfall occurred on an average of 36 days at all sites, or one day out of 5. During the winter period 50 per cent of the storms at Rifle occurred at 1-to-2-day intervals, and more than 90 per cent of the storms at Rifle occurred at 1-to-7 day intervals (Table 4). At Rifle the longest time between rains for the winter period was 16 days (October 7-22) as compared to 30 days (May 10-June 9) for the summer period. Table 3 also shows the difference in amounts of rain at each site for each storm. Although there is often considerable difference by storms the total amount of rainfall for the period is about the same for all sites.

Table 5 gives the rainfall by storm classes. Mound had 4 storms more than Rifle and 6 more than Park. Storms with 1 to 2 in. of rainfall accounted for the greatest percentage of the total rainfall for the period at Park. The greatest percentage at Rifle and Mound came from the .51- to 1.00-in. storms.

Table 4

NUMBER AND INTERVALS OF STORMS AT RIFLE

	Number of Days Between Storms										
	1	2	3	4	5	6	7	8	10	11	16
No. of storms for winter period	14	9	4	3	4	4	4	1	1	1	1

Table 5

PRECIPITATION BY STORM CLASSES

	Park			Rifle			Mound		
Storm Class (In.)	No. of Storms	Amt (In.)	% of Total Amt	No. of Storms	Amt (In.)	% of Total Amt	No. of Storms	Amt (In.)	% of Total Amt
0.00 - 0.25	24	1.91	8.9	24	1.95	9.2	31	2.55	12.4
0.26 - 0.50	9	3.15	14.7	11	4.24	19.9	7	2.48	12.0
0.51 - 1.00	8	6.02	28.1	10	7.65	36.0	11	7.40	35.8
1.01 - 2.00	7	10.33	48.3	4	5.36	25.2	4	6.16	29.8
2.01 - 3.00	-	-	-	1	2.07	9.7	1	2.06	10.0
3.01 - 4.00	-	-	-	-	-	-	-	-	-
Total	48	21.41	100.0	50	21.27	100.0	54	20.65	100.0

Table 6 gives the 10 highest intensities for 2- to 12-min intervals at each site. The intensities for the winter period were considerably lower than for the summer period. During the summer at Rifle, for instance, 50 per cent of the rainfall fell between intensities of 1.75 and 6.0 in. per hr. Comparable winter values are .25 and 3.80 in. per hr. Intensities were usually higher at Mound than at the other sites, which was also true for the summer period. Figure 1 shows the intensity-duration relationships for the major part of the rainfall for 2 typical storms. Figure 2 shows the relation of minimum rainfall intensity to storm size and per cent of storm rainfall. At each site only about 20

Table 6

MAXIMUM RAINFALL INTENSITIES

Park			Rifle			Mound		
Date	Intensity (In./Hr)	Interval (Min)	Date	Intensity (In./Hr)	Interval (Min)	Date	Intensity (In./Hr)	Interval (Min)
3/3	6.60	2	10/23	3.80	3	12/8	4.20	5
12/7	3.86	7	10/3	3.80	3	11/14	3.90	2
12/14	3.00	3	12/7	3.60	3	3/29	3.70	6
12/7	2.40	5	3/3	3.60	2	12/7	3.38	8
12/8	2.25	8	12/7	3.27	7	12/3	3.00	2
12/7	2.10	2	12/8	2.25	4	12/3	2.40	3
12/14	1.80	11	10/23	2.16	5	12/3	2.40	2
1/20	1.80	5	12/20	2.13	12	12/7	2.16	5
12/20	1.72	8	1/27	2.04	5	11/14	2.10	4
3/22	1.71	7	2/12	2.00	3	12/7	2.00	3

per cent of the rainfall in storms over 0.25 in. occurred at intensities of 1.00 in. per hr or more. At all sites about 50 per cent of the total rainfall came from intensities of 0.50 in. per hr or less.

Air Temperature

The daily record of the maximum and minimum air temperature is given in Figure 3, and the average monthly values are given in Table 7. There was very little difference in air temperatures at the 3 sites. Mound temperatures were usually a little lower than Park and Rifle. A comparison with the long-time record shows that the average maximum and minimum temperatures for the three main winter months, December, January and February, were 2 to 8 degrees higher than the average. The first frost of the period came on November 3. The number of frosts for the entire period was none in October, 11 in November, 9 in December, 5 in January, 2 in February and 2 in March. Air temperatures were about 15 degrees F higher during October than for the other months during the period. The

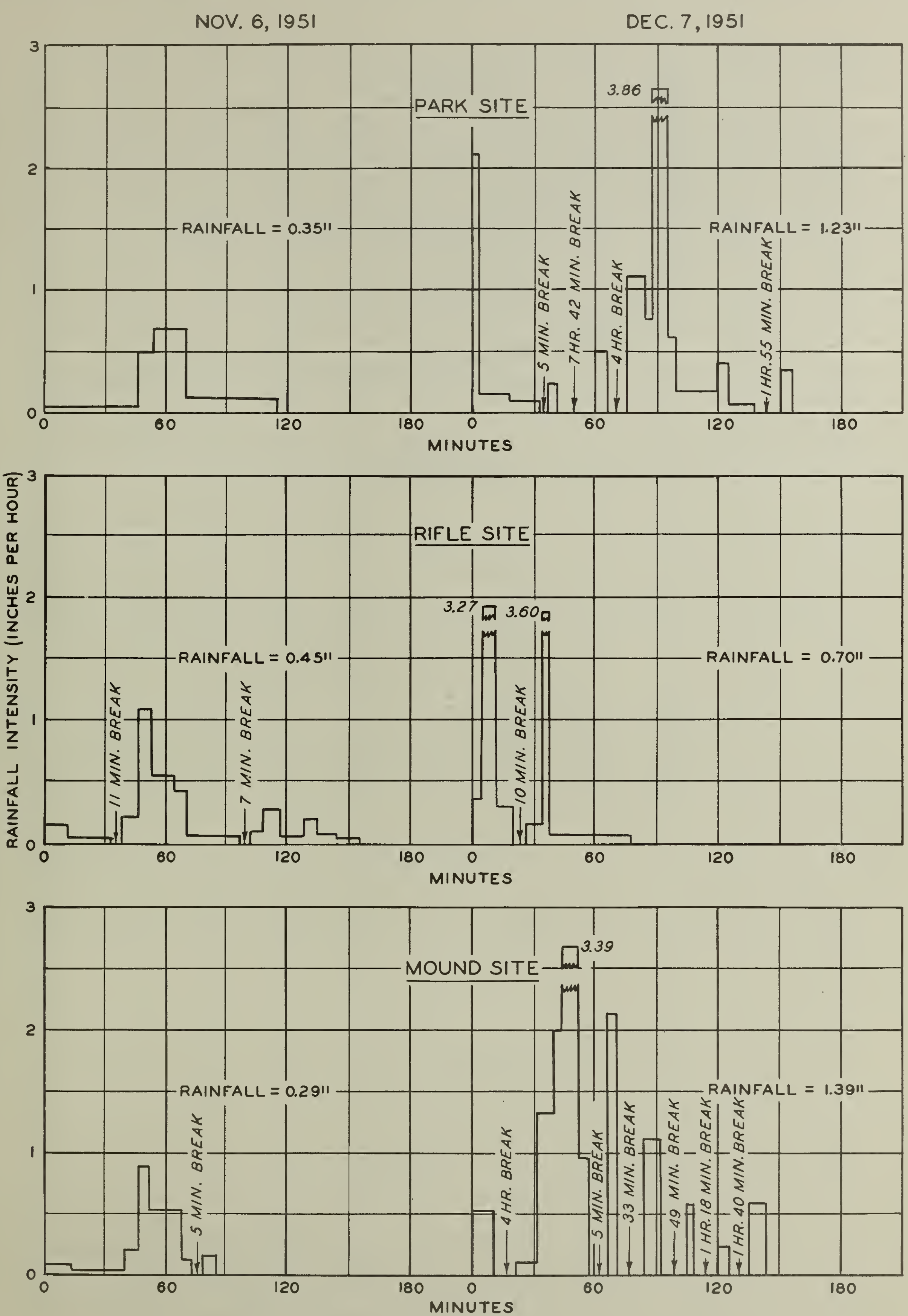

FIGURE I. INTENSITY-DURATION RELATION OF 2 TYPICAL STORMS

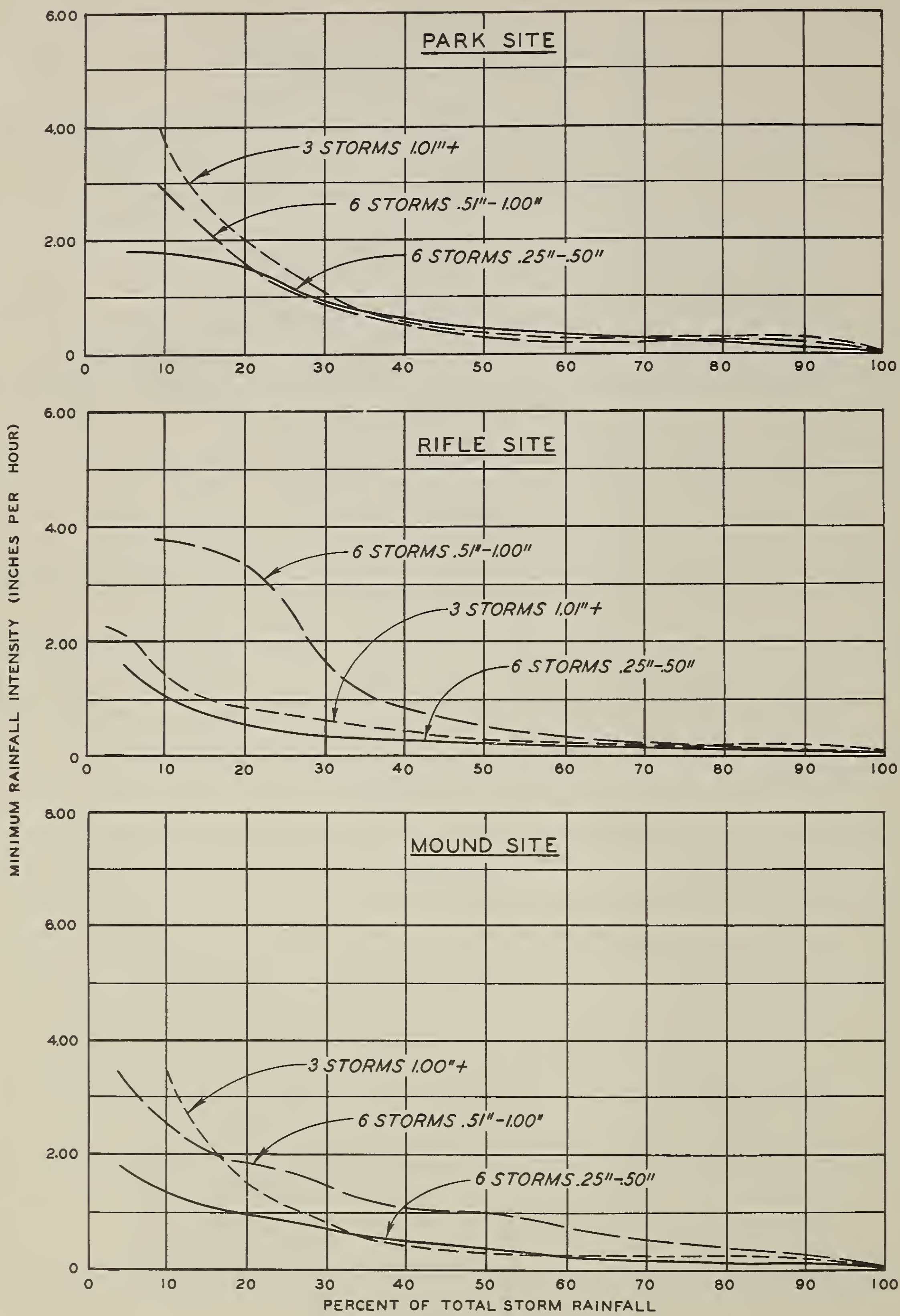

FIGURE 2. RELATION OF MINIMUM RAINFALL INTENSITY TO STORM SIZE AND PER CENT OF TOTAL STORM RAINFALL

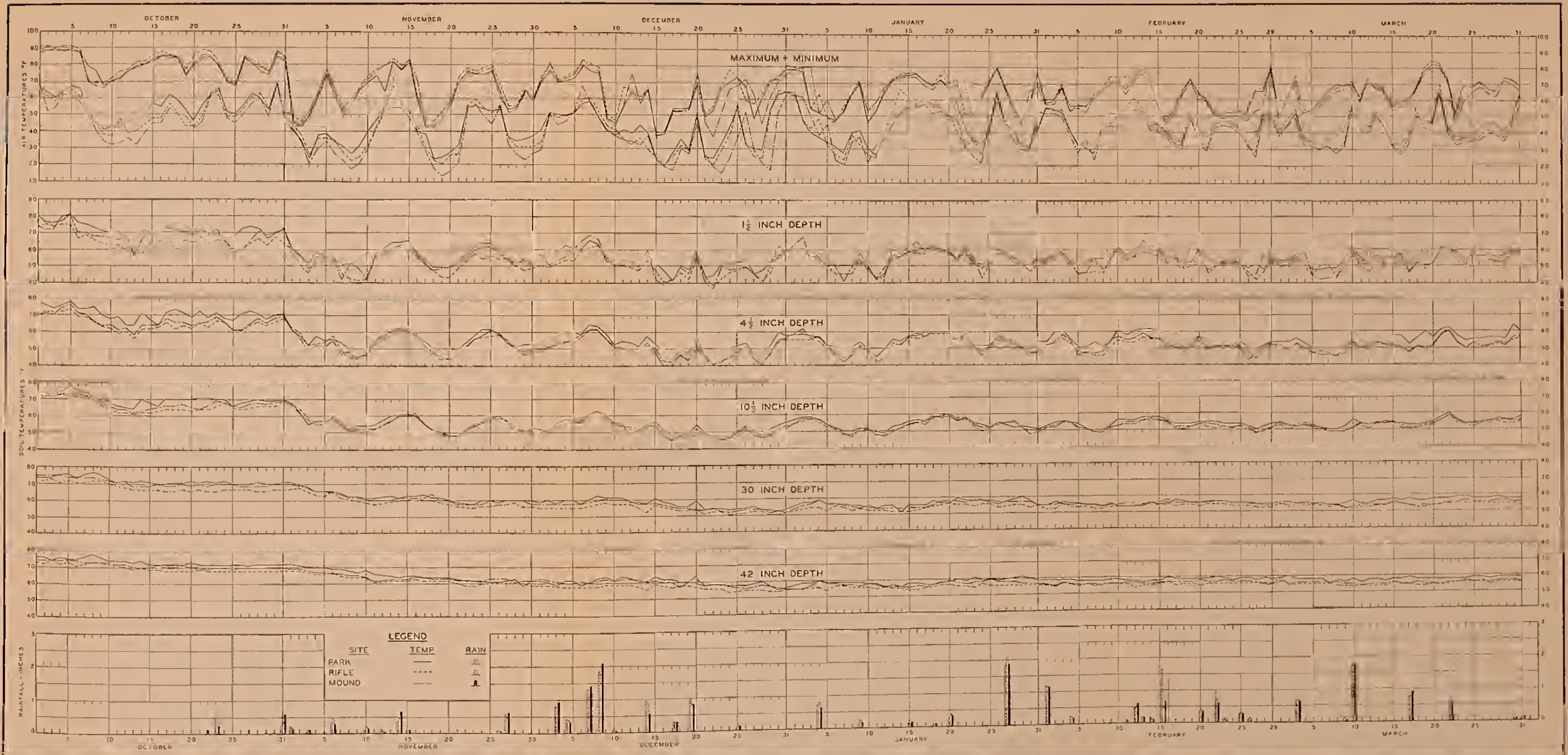

FIGURE 3. DAILY RECORD OF AIR AND SOIL TEMPERATURES AND PRECIPITATION AT EACH SITE

Table 7

AVERAGE MONTHLY AIR TEMPERATURES (IN DEGREES FAHRENHEIT)

Date	Park Max	Park Min	Park Mean	Rifle Max	Rifle Min	Rifle Mean	Mound Max	Mound Min	Mound Mean
October	80.0	55.4	67.7	82.1	52.6	67.4	79.7	49.4	64.6
November	62.6	41.1	51.9	64.7	39.2	52.0	63.7	34.9	49.3
December	63.7	42.2	53.0	65.5	40.3	52.9	62.7	37.1	49.9
January	65.7	46.3	56.0	65.4	43.7	54.6	65.7	42.6	54.2
February	63.2	45.4	54.3	63.8	43.8	53.8	61.1	41.3	51.2
March	66.6	44.1	55.4	66.8	42.1	54.5	63.7	40.6	52.2

Date	Vicksburg Max	Vicksburg Min	78-yr Avg Max	78-yr Avg Min
October	78.9	58.0	76.9	57.1
November	62.4	42.6	66.2	47.2
December	63.7	43.5	58.5	41.8
January	64.6	46.5	57.1	40.3
February	63.4	47.6	60.2	42.8
March	66.3	47.1	67.7	49.3

high temperatures in October were more like the summer period than the winter period. After October there was very little variation in the mean monthly air temperatures. The extremes for the period were 91 degrees F at Rifle on October 1, 2, 4, and 5, and 14 degrees F at Mound on November 19.

Soil Temperature

Figure 3 gives the daily soil temperatures at each site for the 1-1/2, 4-1/2-, 10-1/2-, 30- and 42-in. depths. The greatest variation was in the 0-3-in. depth. Like the air temperatures, the soil temperatures were 10-15 degrees F higher for October than for the other months of the period. Table 8 gives the average monthly soil temperatures and minimum soil temperatures for all sites. At the beginning of the period in October, the

Table 8

AVERAGE MONTHLY SOIL TEMPERATURES FOR ALL SITES (IN DEGREES FAHRENHEIT)

Site	October	November	December	January	February	March
			1-1/2-in. Depth			
Park	72.4	56.4	54.2	54.2	55.1	55.4
Rifle	65.7	52.9	50.1	52.8	51.5	51.6
Mound	69.4	54.8	51.9	54.6	54.1	53.2
			4-1/2-in. Depth			
Park	71.0	56.0	53.8	54.8	55.9	56.2
Rifle	65.1	53.1	49.9	52.0	51.1	51.2
Mound	66.3	52.8	49.5	52.3	51.8	51.2
			10-1/2-in. Depth			
Park	70.0	55.8	53.6	54.2	54.2	54.2
Rifle	66.1	55.7	51.9	53.3	52.3	53.3
Mound	67.6	55.2	51.4	53.2	52.6	52.8
			30-in. Depth			
Park	72.2	62.8	58.0	56.8	55.9	56.9
Rifle	68.3	60.2	54.8	54.4	54.2	54.1
Mound	71.1	62.0	56.3	56.2	55.6	54.9
			42-in. Depth			
Park	73.4	65.4	60.5	58.9	58.9	58.0
Rifle	69.8	62.7	57.1	55.1	55.1	55.1
Mound	71.3	64.1	59.4	57.1	56.5	55.7
			Minimum Temperatures			
Park	64	48	42	43	48	48
Rifle	56	42	39	43	42	44
Mound	56	42	37	41	43	42

soil temperature was fairly uniform at all depths. In November the lower air temperatures are reflected in the drop in soil temperature throughout all depths. Note, however, the considerable lag at the 30- and 42-in. depths. The temperatures were not uniform again at all depths until March.

The temperatures at Park for all depths were about 1-6 degrees F higher than at Rifle and Mound. This was probably due to its southeasterly exposure.

Humidity

The daily record of relative humidity at all sites was converted to absolute humidity and saturation deficit, expressed in grams per cubic meter, and plotted for the 6-month period (Figure 4, pages 19 and 20). The greater variation in absolute humidity than in saturation deficit appears to be related to variation in temperature. As cloud cover increases the absolute humidity increases. Wind velocity appears to affect the absolute humidity; as the wind velocity increases the absolute humidity decreases.

Wind Movement

The daily record of wind velocities at Rifle and Mound at the 4-, 8-, and 16-ft heights for the 6-month period is given in Figure 4. Velocities were much lower at Rifle than Mound, which was also true for the summer period. Mound site is much more exposed to the wind. Wind velocities increased with height, the difference being greater at the higher velocities. Table 9 gives the average monthly wind velocities for the 6-month period. The wind velocities for the winter period were much higher than for the summer period. The average for the 16-ft level at Mound was 5.79 miles per hour for the winter period and 3.85 miles per hour for the summer period.

Cloud Cover

A cloud cover index was plotted from data obtained at the Vicksburg Weather Bureau (Figure 4). The daily index represents an average of estimates of cloud cover to the nearest 10 per cent taken every daylight hour. The number of clear days, cloudy and partly cloudy days for each month is given in Table 10.

Table 9

AVERAGE 24-HOUR WIND VELOCITY

Date	Rifle — Wind Velocity, mph, at Instrument Heights of 4 ft	8 ft	16 ft	Mound — Wind Velocity, mph, at Instrument Heights of 4 ft	8 ft	16 ft
October	.87	1.10	1.49	1.65	2.45	3.34
November	1.68	2.14	2.84	3.02	4.12	5.37
December	2.58	3.23	4.10	4.25	5.48	6.89
January	2.40	2.98	3.72	3.96	5.03	6.33
February	2.24	3.61	3.81	3.97	5.01	6.18
March	2.24	3.02	3.67	4.38	5.45	6.63
Highest 24-hr Average Velocity						
12/30	6.85	8.57	10.53	-	-	-
3/1	-	-	-	9.19	11.55	14.00
Lowest 24-hr Average Velocity						
10/6	.39	.53	.95	-	-	-
10/6	-	-	-	.30	.35	.77

Table 10

CLOUD COVER

Month	No. Days Clear	No. Days Partly Cloudy	No. Days Cloudy
October	14	7	10
November	9	8	13
December	8	9	14
January	2	8	21
February	4	9	16
March	7	9	15

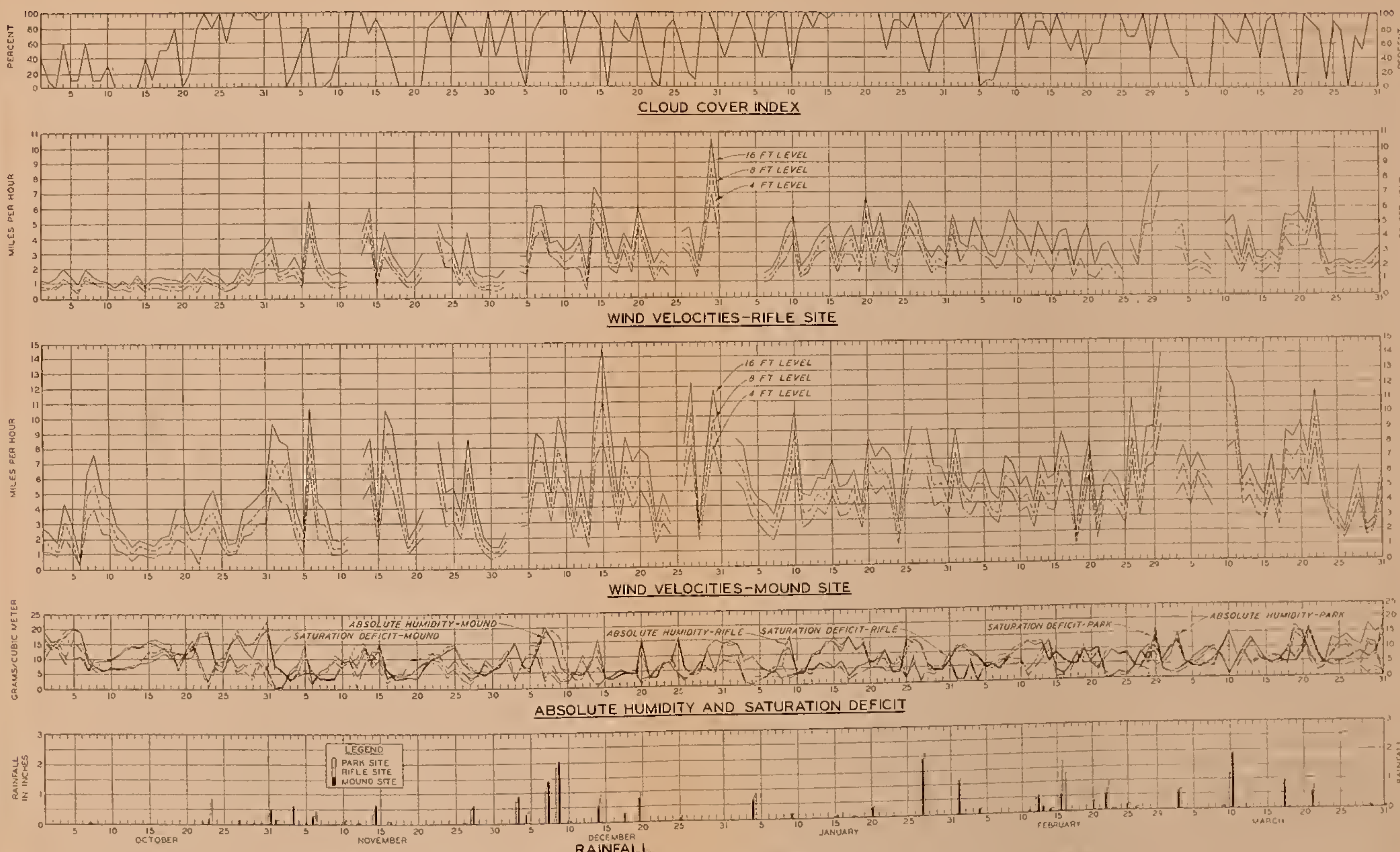

FIGURE 4. DAILY RECORD OF CLOUD COVER, WIND VELOCITY, ABSOLUTE HUMIDITY, SATURATION DEFICIT AND PRECIPITATION AT EACH SITE

VEGETATION

The influence of vegetation in determining the rate and extent of soil moisture depletion has been recognized and discussed in Progress Report I. In order that further relations between this influence and soil water depletion might be charted, the study of vegetation species and development at the three sampling sites was continued throughout the period from October 1, 1951, to April 1, 1952.

The same methods and procedures were used in making vegetal observations during the winter period as in the preceding summer period and reported in Progress Report I. Field examinations were made monthly, and more frequently after growth began, of each species occupying the test site.

Vegetation, which is herbaceous in nature at all sites, responded to the relatively mild winter in this area. After the first killing freeze in early November, all sites were generally void of green or live vegetation for approximately one month's duration. The first plant emergence came in December, followed by some growth in each month of January, February, and March.

The principal species on the sites for October, or preceding the killing frost, were for Park, *Paspalum* sp., Dallis grass, and *Cynodon* sp., Bermuda grass; for Rifle, *Sorghum* sp., Johnson grass, and *Paspalum*; for Mound, *Aster* sp., *Sorghum*, and *Cynodon*.

After the killing frost in November all sites were practically covered with dead plant material.

At Park, first emergence in December was noted for *Vicia* sp., vetch,

Hordeum sp., wild barley, Erigeron sp., fleabane, Medicago sp., California burclover, and Allium sp., wild onion. At Rifle, the first plants to emerge in December were Hordeum, Sorghum, Rudbeckia sp., coneflower, Oenothera sp., evening primrose, Carex sp., sedge, and Rumex sp., dock. At Mound first emergence was made by Aster, Vicia Trifolium sp., white clover and Lathyrus sp., pea.

Plant growth progressed slowly in January and February, and attained its maximum rate in March. Average March height, density in per cent of ground surface covered, flowering and fruiting for the principal species of each site are shown in Table 11.

Table 11

CHARACTERISTICS OF PRINCIPAL VEGETATION AT PARK, RIFLE, AND MOUND SITES IN MARCH

Species	Per Cent of Ground Surface Covered	Height in In.	Flower and Fruit Condition
	Park		
Hordeum sp., wild barley	50	6	Flowering and fruiting
Vicia sp., vetch	16	8	Flowering
Paspalum sp., Dallis grass	12	3	
	Rifle		
Rudbeckia sp., coneflower	22	10	
Hordeum sp., wild barley	9	8	Flowering and fruiting
Sorghum sp., Johnson grass	7	15	
	Mound		
Aster sp.	25	5	
Vicia sp., vetch	20	10	Flowering
Trifolium sp., white clover	16	3	Flowering
Lathyrus sp., pea	10	14	Flowering

Species listed in Table 11 tie in well with those reported as dominant early in the period covered by Progress Report I. It was shown at that time that *Hordeum* was the principal species at Park, *Rudbeckia* at Rifle, and *Aster* and legumes at Mound.

SOIL CLASSIFICATION OF SITES

In Progress Report I, the soils under investigation were tentatively identified on the basis of a Soil Survey map of 1912, the most recent detailed map published in this area. On this map the upland loess soils were named Memphis, the alluvial bottomlands within this loess region were named Vicksburg, and the alluvial deposits from the Mississippi River were largely Sharkey.

In March 1952 the soils were classified* recognizing differences in slope, development and parent material which were not considered in the early classifications. Although new soil series names had been established for these variants, they are closely related to the previously named series from which they were subdivided. A useful grouping of these soils is the catena. Soils of a catena occur within one zonal region having developed from similar parent material but differing in degree and character of profile development owing to the differences in relief or drainage. The following classification uses this concept to show the relationship between past and present soil names.

Park Site

The soils at the Park site are variants within the Memphis catena. On the slope the soil is a Loring silt loam, strongly sloping, alkaline substratum phase. The Loring differs from the Memphis in having a slightly compact subsoil with less perfect drainage. Because of imperfect

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* Classifications and descriptions were made in the field by Mr. Irving L. Martin, Senior Soil Correlator, Southern States, of the Division of Soil Survey, BPISAE.

drainage the subsoil is mottled with splotches of gray and yellow.

On the flat the soil is Grenada silt loam, eroded level alkaline substratum phase. The Grenada differs from the Memphis and Loring in that it has a very compact layer below the subsoil. Because of this layer the soil is less well-drained than the Loring. At the time of identification in early March, the soil within and below this layer was relatively dry pointing out the imperviousness of this compact layer. The subsoil is highly mottled and grayer than the Loring. A description of the Park site soils follows:

Slope

Loring silt loam, strongly sloping alkaline substratum phase.

1. 0 to 8 in.	Light yellowish-brown very friable silt loam; weak fine granular structure.
2. 8 to 14 in.	Brownish-yellow light silty clay loam; moderate to weak medium blocky structure.
3. 14 to 32 in.	Strong brown silty clay loam; moderate medium blocky structure; medium acid; resting abruptly upon:
4. 32 to 48 in.	Very pale brown very firm silt loam; highly mottled with shades of gray and yellow.
5. 48 in. +	Light yellowish-brown alkaline silt loam.

Flat

Grenada silt loam, eroded level alkaline substratum phase.

1. 0 to 4 in.	Light yellowish-brown friable silt loam.
2. 4 to 24 in.	Brownish-yellow silty clay loam; moderate to medium blocky structure; resting rather abruptly upon:
3. 24 to 44 in.	Light gray very firm (compact) silt loam

	mottled with shades of brown and yellow.
4. 44 in.+	Light yellowish-brown alkaline silt loam.

Rifle Range Site

The soil at Rifle Range site was found to be of fill material for the first 16 in., presumably from the construction of the roadway and drainage ditch, consequently it was classified as "made land." The subsoil and soil drainage resemble those of Collins silt loam, a member of the Vicksburg catena. The Collins differs from the Vicksburg in being less well-drained with a lighter colored, more mottled subsoil. A description of the soil follows:

Made land, Collins drainage.

1. 0 to 8 in.	Brown silt loam.
2. 8 to 16 in.	Yellowish-brown silt loam slightly mottled with shades of gray and brown.
3. 16 to 24 in.	Gray and yellow mottled silt loam.
4. 24 to 110 in.	Light gray silt loam mottled with shades of brown and gray.
5. 110 in.+	Olive gray to black silty clay loam.

Mound Site

The soil at Mound site is Commerce clay, overwash phase. The site occupies a broad natural levee. With a shifting of the river bed, the site had been covered with 12 to 14 in. of dark gray clay, deposited in slack-water. This slack-water deposit is Sharkey material which formed

the basis of the original classification. Below 12 in. the soil has been derived from materials of the natural levee. It is brown, coarser in texture, and better drained than the Sharkey. The surface material is consequently also better drained than a Sharkey clay soil. A description of the soil follows:

Commerce clay, overwash phase.

1. 0 to 6 in.	Dark grayish-brown sticky clay; weak medium to fine granular structure; with a few faint mottles; slightly acid to alkaline.
2. 6 to 14 in.	Dark gray sticky clay; weak medium to coarse subangular blocky structure; slightly acid to alkaline.
3. 14 to 38 in.	Grayish-brown silty clay loam mottled with shades of gray, yellow, and brown; structureless; neutral to alkaline.
4. 38 in. +	Grayish-brown silt loam; mottled with shades of gray, yellow, and brown; structureless; neutral to alkaline.

Extent of Soils

The extent of these soils in the Lower Mississippi Valley is shown in Figure 5. The areas of Memphis-Vicksburg and associated soils are shown by vertical lines, and the areas of Sharkey-Commerce and associated soils are shown by horizontal lines.

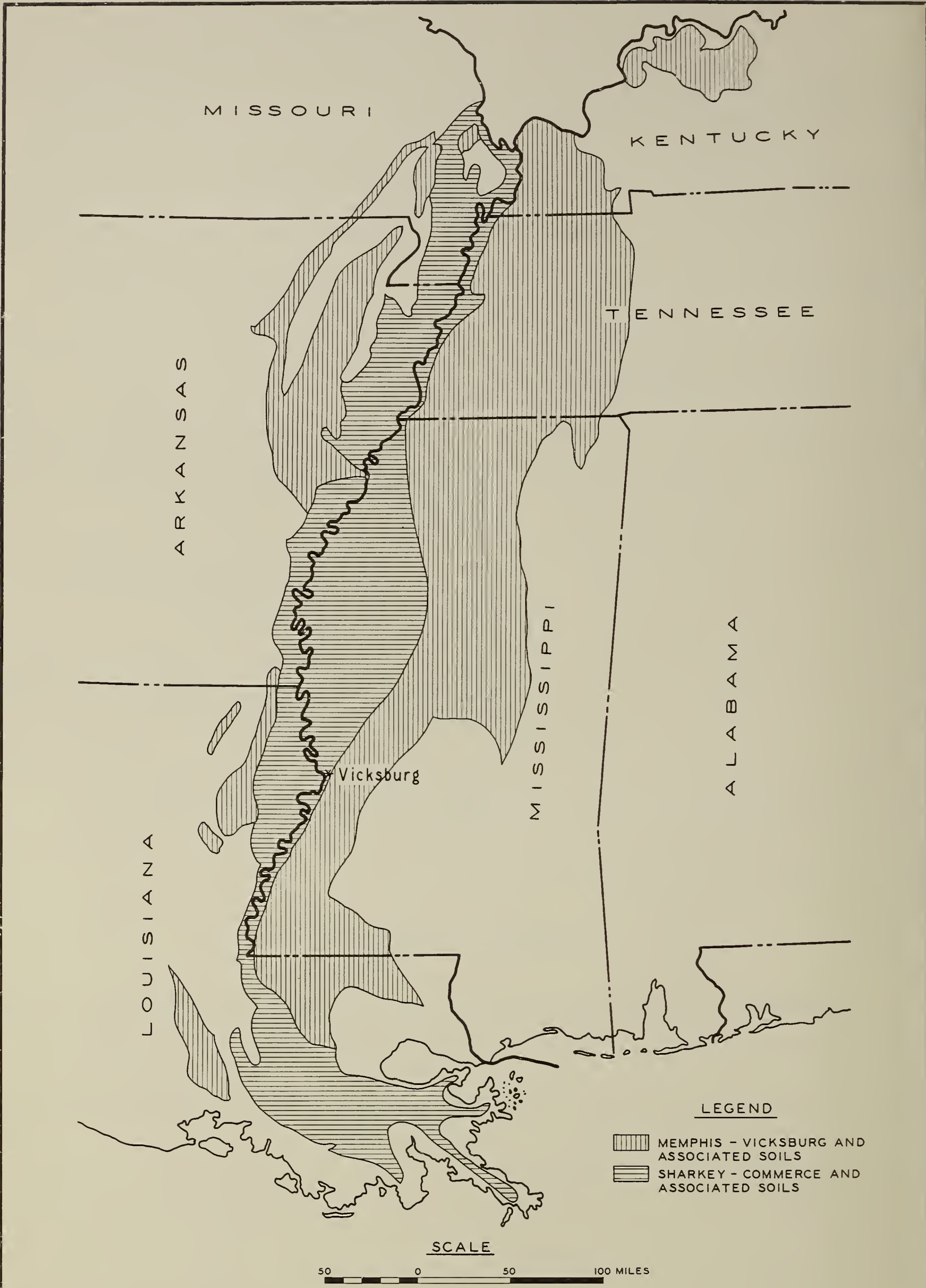

FIGURE 5. EXTENT OF SOILS UNDER INVESTIGATION

SOIL MOISTURE RECORD

The accompanying Figures 6, 7, and 8 show the daily march of soil moisture for the period October 1, 1951 to April 1, 1952 for the 0- to 3-, 6- to 9-, and 9- to 12-in. depths at Park, Rifle, and Mound.

Park

Depletion rates typical for the growing season condition continued through October until the rain on the 23rd. This storm wetted the 0- to 3-in. layer and partially and erratically wet the lower depths. Intermittent rainfall thereafter continued the wetting process and early in December (rain on December 7 and 9) all depths were wetted to near maximum values. For the remainder of the period, moisture contents remained high. After rainfalls, depletion occurred at a high rate from near saturation to field capacity; after reaching field capacity the depletion rate was very slow for the short interval before the next rainfall. Depletion during March was found to be at a rate intermediate between winter and summer rates.

Rifle

Summer depletion rates prevailed during most of October. The October 23 storm resulted in high moisture contents in the 0- to 3-in. depth and intermediate values in the 6- to 9-in. depth. The 9- to 12-in. depth showed a moderate but delayed rise in moisture content. By early December all depths were wetted to near maximum values and alternate wetting and moderate depletion occurred through the rest of the period in much the

same manner as at Park.

Mound

Summer depletion occurred throughout October, slight rainfall in the latter part of the month affecting appreciably only the 0-3-in. depth. Moisture contents fluctuated through November gradually increasing until early December when maximum moisture contents were reached. Alternate wetting and moderate depletion prevailed for the rest of the period. The effect of the water table was pronounced early in February when depletion would have been expected but did not occur because of the high water table.

Summary

At all sites, relatively low moisture contents prevailed in October; periodic wetting occurred through November and high moisture contents typical of the winter season were reached early in December. Thereafter, moisture contents stayed relatively high as the periods between rainfalls were short and rates of depletion were low. In March, when vegetation again began to grow, rates of depletion increased sufficiently to occupy a position intermediate between winter and summer conditions.

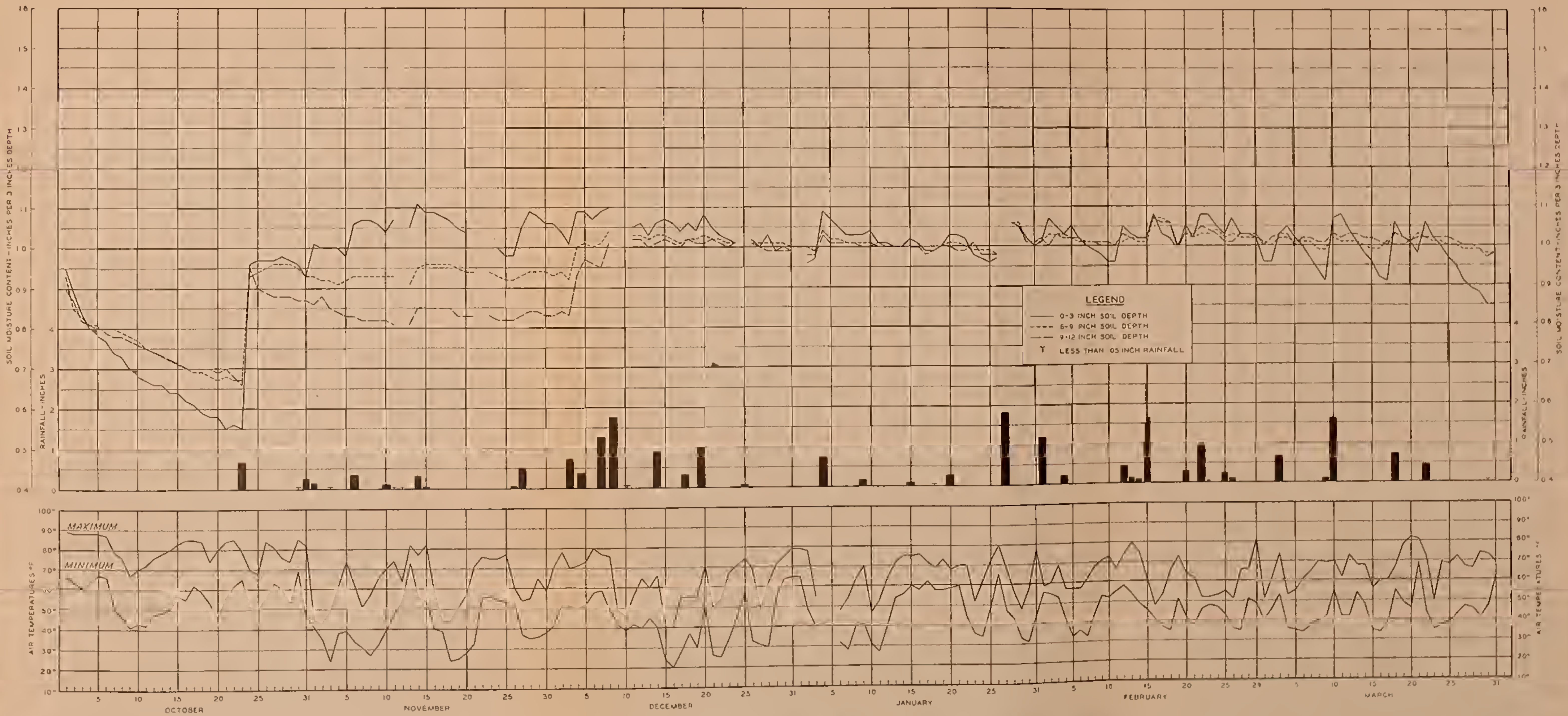

FIGURE 6. DAILY MARCH OF SOIL MOISTURE AND AIR TEMPERATURES AND RELATION TO RAINFALL DURING WINTER SEASON— PARK SITE

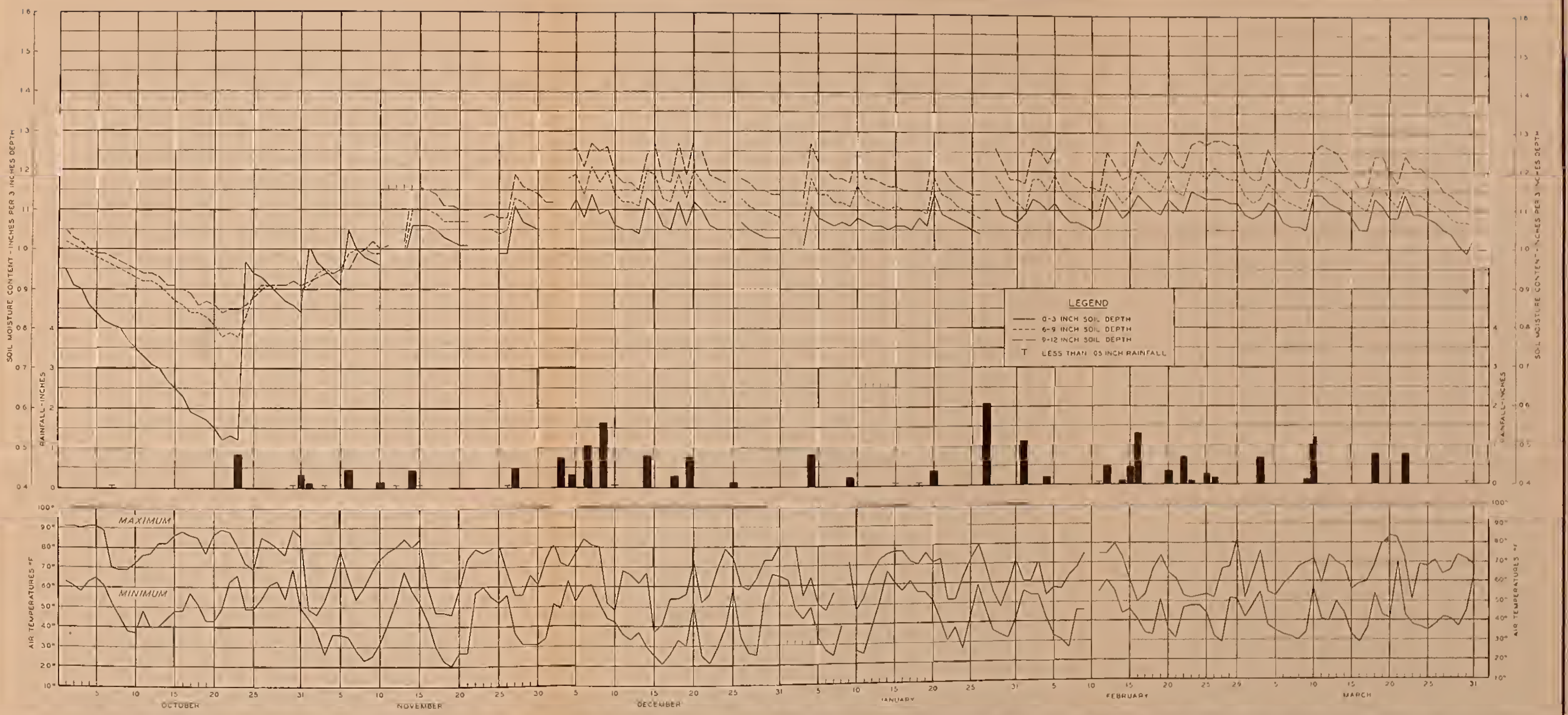

FIGURE 7. DAILY MARCH OF SOIL MOISTURE AND AIR TEMPERATURES AND RELATION TO RAINFALL DURING WINTER SEASON - RIFLE SITE

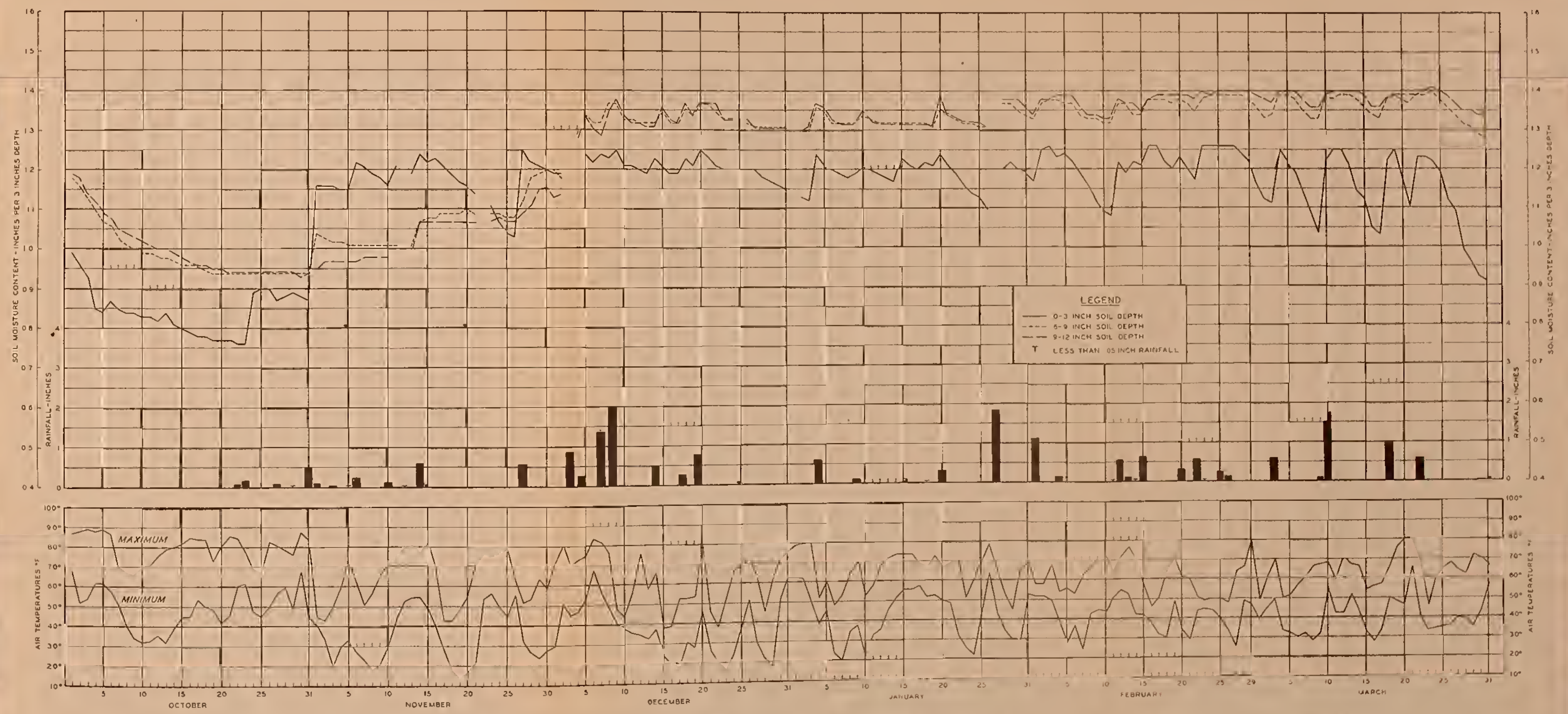

FIGURE 8. DAILY MARCH OF SOIL MOISTURE AND AIR TEMPERATURES AND RELATION TO RAINFALL DURING WINTER SEASON — MOUND SITE

WATER TABLES

Progress Report I describes the observation wells at Rifle and Mound and the well records for the summer period. This record was continued through the October 1-April 1 period.

Rifle

Figure 9 presents the well record for Rifle. Ground water levels for those wells dug to depths of about 10 ft were observed. Late in February two shallow wells were dug, one of one-foot depth, the other of 3-ft depth, in order to detect the presence of a shallow perched water table if one existed.

It will be noted in Figure 9 that the water level in Well No. 2 rose much higher after each rain than the level in the other wells. This is believed due to lateral flow into the well from the surface soil layers. In the course of 3 to 4 days it dropped to approximately the level of the other wells.

Through October and November the water level remained about 9 or 10 ft below the surface. The heavy rains of December 7 and 9 served to raise the level markedly; later rains added to this and at the end of the month the water level was at about 5 ft. Through January it held generally at 4-1/2 to 5 ft. Through February and March the level fluctuated considerably, most of the time between the 1-1/2- and 3-ft depths.

This high water table through most of the winter period points up the reduced effect of evapo-transpiration, especially since rainfall during the 6-month period this year was less than that for the preceding six

months.

The records from the 1- and 3-ft wells do not indicate the presence of a perched water table. At no time during the period of record was water observed in the 1-ft well.

Late in February, a staff gage was placed in the creek adjacent to the experimental site. The record of the creek level is included in Figure 9. It will be noted that for the period of record the creek level was generally above that of the water in the wells. This indicates that the experimental site is subject to subsurface inflow from the creek.

A test of soil permeability was made on Well No. 2 in March. The water level was lowered approximately 2 ft by bailing. Within an hour, the water was back almost to its original level, indicating that the soil permeability is sufficient to reflect water table changes with only a short time lag.

Mound

Figure 9 also shows the observation well data for Mound. Two wells of 10-ft depth were maintained at this site, and 1- and 3-ft wells were added in February as at Rifle. At the same time a staff gage was installed in a shallow ditch adjacent to the experimental site.

The most striking feature of the well record of Mound is the difference between water levels in Wells Nos. 1 and 2. It was noted last May and June that it apparently took several weeks after digging these wells for them to reflect the water table. Well No. 2., dug later than No. 1., took a month (June) to reach a level equivalent with No. 1, after which the fluctuations in the two wells corresponded closely. This indicates

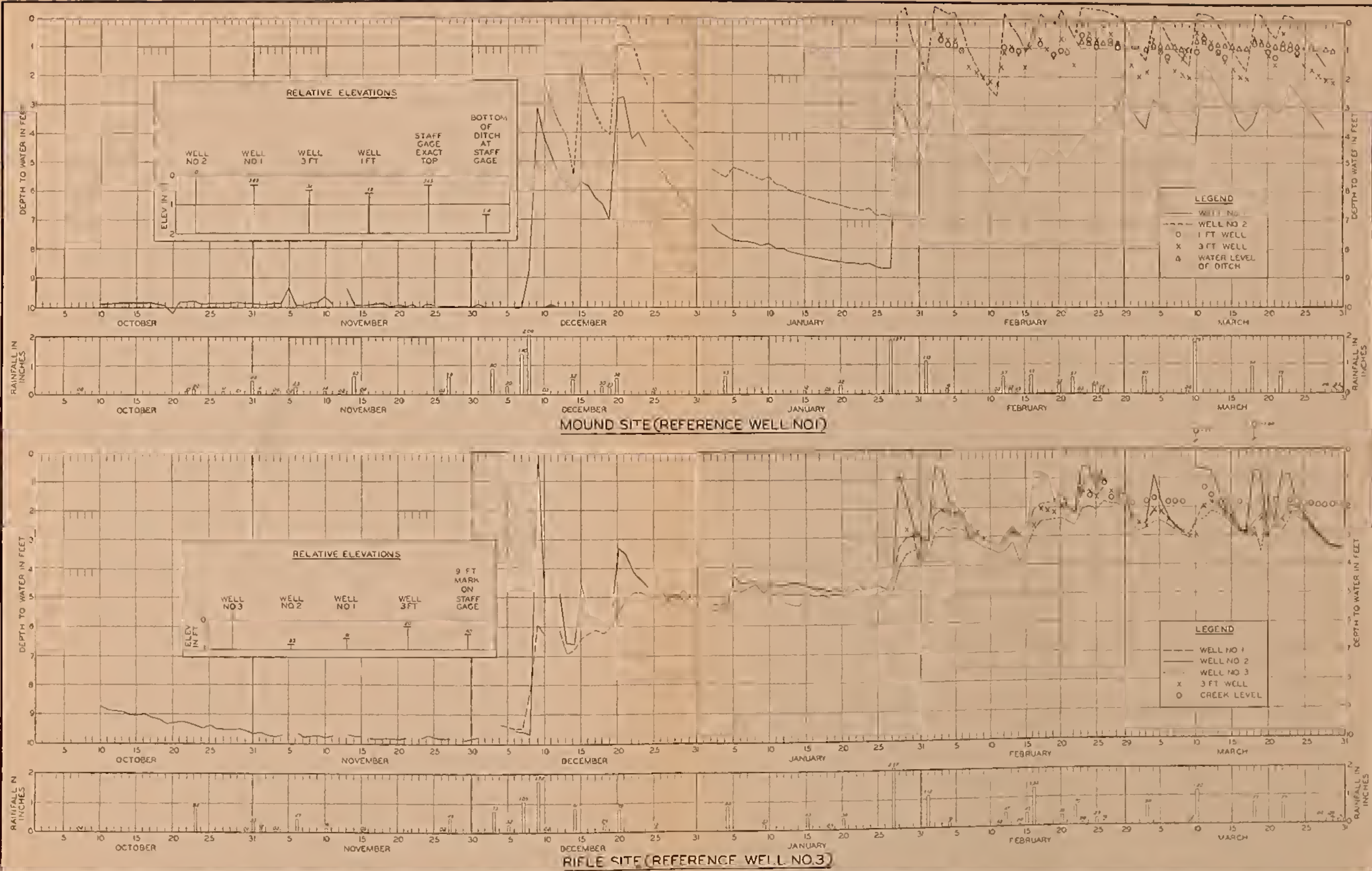

FIGURE 9. DISTANCE FROM SOIL SURFACE AT REFERENCE WELL TO WATER LEVEL IN WELLS, DITCH OR CREEK

the low soil permeability at Mound which causes equilibrium to be reached very slowly.

Very slow rates of recovery were found in the Mound wells when the water tables were artificially raised or lowered in tests made in March.

Well No. 2 at Mound is probably affected by influence of lateral flow through the upper soil layers in the same way as Well No. 2 at Rifle. However, the data from Well No. 2, the 1- and 3-ft wells, and the ditch all indicate a temporary perched water table. It seems logical to expect that, if longer periods occurred between rainfalls, Well No. 2 level would recede to that of Well No. 1.

As at Rifle, the water table at Mound was below 9 ft until the rains of December 7 to 9. It reached a high on December 20 (water table apparently at 3 ft), then receded gradually to almost 9 ft again on January 27. From then to the end of March it fluctuated considerably. From observation of other shallow wells, a perched water table of temporary character was maintained within 2 ft of the surface by frequent rainfalls.

SOIL MOISTURE ACCRETION UNDER WINTER CONDITIONS AS AFFECTED BY RAINFALL

The methods of predicting soil moisture content after winter storms follow those used in the analysis of summer storms. In brief, first, the storms were classified considering the amount of rainfall and available storage capacity. Then for each classified storm, the accretions in 3-in. layers from 6 to 15 in. were estimated, using, in general, the same relationships derived for summer storms. The predicted accretions were then compared with actual accretions at these depths.

During the period October 1 to April 1, there were 27 storms at Park for accretion analysis, 28 at Rifle, and 25 at Mound. As with summer data, only storms of .25 in. or greater were analyzed for their effect on soil moisture content. The methods of calculating accretion and available storage were identical to those used in the summer analysis.

The total rainfall rather than the "through" rainfall became the index of water available for accretion under winter conditions for several reasons. With lower temperatures, higher humidities, and more cloud cover, evaporation was less in winter than in summer. Following the first frost, vegetation was killed or retarded in growth, so that rainfall interception was less than in summer. Also rainfall data for small storms in this period indicated little interception. In the subsequent analysis, therefore, the total rainfall is considered as having reached the soil. The small interception that occurs does not affect the prediction.

From the data of storm size, accretion, and available storage space, the storms under winter conditions fall into two classes with

respect to the amount of water added to the 6- to 15-in. depth.

Class I-W. Storms for which total rainfall is less than available storage in the 0- to 12-in. depth.

Class II. Storms for which total rainfall is equal to or greater than available storage in the 0- to 12-in. depth.

In winter the available storage is very low, consequently a given storm either very slightly wets the 6- to 15-in. depth (Class I-W) or it fully satisfies the available storage space (Class II), thus giving rise to the two storm classes. In general, the available storage in the 0- to 12-in. depth prior to the storm is very low in winter compared with summer, averaging 0.50 against 1.50 in., consequently the conditions for intermediate partial wetting do not occur in winter as in summer with Class III storms. Because of the lack of Class III storms in winter, the specifications of Class I storms were changed to consider available storage in the 0- to 12-in. depth rather than in the 0- to 6-in. depth as in summer, in order to include all storms in the two classes. This change did not affect the placement of storms normally falling in the Class I category.

Rainfall, available storage, and accretion are given in Tables 12, 13, and 14 for each storm and each site in chronological order by storm classes.

With several of the storms at all sites, accretion amounting to about 0.02 in. throughout the 0- to 15-in. depth occurred the second and third days following a storm, particularly at lower depths. This was in part compensated by depletion at the shallower depths, indicating a slow drainage of soils wetter than field capacity. Moisture content on the day following a storm was used for the analysis of accretion at all depths.

Table 12

RAINFALL, AVAILABLE STORAGE, AND ACCRETION BY STORM CLASSES, PARK SITE

Date of Storm	Rainfall In.	Available Storage 0-12 In.	0 - 6 In. Available Storage	0 - 6 In. Accretion	6 - 9 In. Available Storage	6 - 9 In. Accretion	9 - 12 In. Available Storage	9 - 12 In. Accretion
			Class I-W Storms					
10/23	.73	1.76	1.03	.49	.35	.12	.38	.23
10/31-11/1	.42	.73	.41	.07	.14	.00	.18	.00
11/6	.35	.66	.31	.07	.13	.01	.22	.00
11/14	.37	.56	.18	.09	.14	.01	.24	.04
11/27	.53	.66	.26	.12	.17	.01	.23	.01
12/7A	.25	.27	.10	.04	.08	.01	.09	.00
12/14A	.25	.28	.17	.06	.06	.02	.05	.01
1/20	.29	.36	.23	.06	.08	.00	.05	.00
			Class II Storms					
12/3	.80	.60	.20	.10	.18	.08	.22	.10
12/4-12/5	.40	.27	.08	.01	.07	.01	.12	.04
12/7P	1.07	.23	.06	.03	.07	.05	.10	.06
12/8-12/9	1.70	.09	.03	.00	.02	.00	.04	.03
12/14P	.64	.20	.11	.01	.05	.00	.04	.01
12/17-12/18	.31	.22	.12	.05	.05	.01	.05	.01
12/19-12/20	.93	.27	.17	.06	.06	.01	.04	.01
1/4	.66	.42	.27	.19	.09	.05	.06	.04
1/27	1.84	.40	.23	.12	.10	.06	.07	.07
2/1-2/2	1.16	.29	.19	.09	.07	.02	.03	.02
2/12	.42	.38	.26	.14	.08	.02	.04	.02
2/15-2/16	1.60	.28	.19	.11	.07	.01	.02	.01
2/20	.30	.27	.18	.08	.08	.02	.03	.02
2/22A	.73	.26	.18	.07	.06	.00	.02	.01
2/25-2/26	.36	.24	.14	.04	.06	.00	.04	.00
3/3	.68	.37	.26	.12	.08	.02	.03	.02
3/10	1.55	.43	.31	.21	.08	.02	.04	.02
3/18	.69	.46	.33	.20	.09	.02	.04	.02
3/22	.46	.33	.23	.10	.07	.02	.03	.01

Table 13

RAINFALL, AVAILABLE STORAGE, AND ACCRETION BY STORM CLASSES, RIFLE SITE

Date of Storm	Rain-fall In.	Avail-able Storage 0-12 In.	0 - 6 In. Avail-able Storage	0 - 6 In. Accre-tion	6 - 9 In. Avail-able Storage	6 - 9 In. Accre-tion	9 - 12 In. Avail-able Storage	9 - 12 In. Accre-tion	12 - 15 In. Avail-able Storage	12 - 15 In. Accre-tion
Class I-W Storms										
10/23/51	.84	2.04	1.15	.76	.44	.05	.45	.01	.29	.00
10/31	.44	1.28	.58	.25	.32	.02	.38	.00	.28	.00
11/6	.47	1.09	.47	.22	.28	.05	.34	.00	.27	.00
11/14	.45	.83	.33	.14	.22	.10	.28	.14	.24	.10
11/27	.49	.68	.30	.20	.17	.10	.21	.10	.19	.09
12/7A	.30	.32	.14	.12	.08	.07	.10	.08	.09	.04
12/14A	.36	.46	.20	.16	.12	.10	.14	.09	.13	.08
12/17	.29	.42	.19	.13	.11	.04	.12	.10	.12	.08
1/20	.38	.46	.19	.15	.13	.10	.14	.12	.13	.10
Class II Storms										
12/3	.73	.54	.23	.10	.14	.08	.17	.11	.15	.10
12/4	.32	.21	.12	.08	.04	.02	.05	.02	.05	.01
12/7(P)	.75	.07	.03	.00	.02	.00	.02	.00	.04	.00
12/8-12/9	1.74	.20	.11	.01	.05	.02	.04	.00	.04	.02
12/14(P)	.45	.11	.04	.00	.02	.00	.05	.03	.04	.03
12/19-12/20	.78	.36	.17	.12	.09	.06	.10	.09	.08	.06
1/4/52	.60	.47	.15	.18	.15	.12	.17	.14	.19	.10
1/27	2.07	.51	.21	.16	.14	.10	.16	.12	.14	.10
2/1	1.06	.38	.14	.09	.12	.08	.12	.08	.11	.08
2/12	.47	.46	.20	.12	.12	.07	.14	.10	.12	.08
2/15-2/16	1.70	.31	.13	.10	.08	.06	.10	.09	.08	.06
2/20	.35	.26	.11	.06	.08	.04	.07	.04	.04	.02
2/22	.70	.30	.13	.12	.08	.06	.09	.06	.04	.04
2/25	.38	.15	.08	.06	.05	.03	.02	.01	.02	.01
3/3	.68	.34	.14	.06	.09	.04	.11	.08	.08	.06
3/9	.82	.46	.20	.15	.12	.10	.14	.10	.12	.07
3/10	.50	.14	.05	.02	.05	.02	.04	.02	.04	.01
3/17	.76	.45	.20	.14	.12	.06	.13	.08	.12	.04
3/21	.77	.29	.12	.12	.08	.05	.09	.07	.05	.04

Table 14

RAINFALL, AVAILABLE STORAGE, AND ACCRETION BY STORM CLASSES, MOUND SITE

Date of Storm	Rainfall In.	Available Storage 0-12 In.	0 - 6 In. Available Storage	0 - 6 In. Accretion	6 - 9 In. Available Storage	6 - 9 In. Accretion	9 - 12 In. Available Storage	9 - 12 In. Accretion	12 - 15 In. Available Storage	12 - 15 In. Accretion
Class I-W Storms										
10/31/51	.65	1.78	.86	.44	.46	.10	.46	.02	.61	.02
11/6	.27	1.23	.42	.08	.38	.00	.43	.00	.56	.00
11/14	.63	1.18	.38	.21	.38	.06	.42	.03	.56	.02
11/27	.59	1.10	.45	.33	.31	.04	.34	.02	.50	.00
12/5	.29	.36	.14	.04	.10	.05	.12	.04	.20	.08
12/18	.30	.32	.16	.06	.08	.04	.08	.05	.11	.03
Class II Storms										
12/3	.89	.66	.20	.07	.20	.10	.26	.14	.45	.25
12/6-12/7	1.40	.28	.13	.06	.08	.05	.11	.06	.17	.08
12/9	2.06	.18	.08	.02	.03	.01	.07	.03	.10	.06
12/13-12/14	.52	.32	.16	.07	.08	.04	.08	.06	.12	.06
12/19-12/20	.66	.26	.13	.08	.06	.03	.07	.04	.10	.07
1/4/52	.55	.47	.27	.19	.10	.06	.10	.07	.13	.11
1/20	.32	.32	.15	.08	.08	.04	.09	.07	.12	.05
1/27	1.87	.45	.27	.17	.09	.06	.09	.07	.12	.10
2/1	1.11	.30	.18	.13	.06	.04	.06	.04	.06	.06
2/12	.60	.46	.30	.20	.08	.06	.08	.05	.09	.07
2/15	.65	.25	.14	.08	.06	.04	.05	.03	.06	.04
2/20	.32	.19	.13	.07	.04	.01	.02	.00	.02	.00
2/22	.60	.22	.16	.14	.04	.03	.02	.02	.02	.01
2/25	.39	.03	.02	.01	.01	.00	.00	.00	.00	.00
3/3	.60	.31	.22	.19	.06	.05	.03	.03	.02	.02
3/10A	.87	.46	.35	.26	.06	.04	.05	.03	.04	.03
3/10P	.98	.12	.08	.05	.02	.01	.02	.01	.02	.01
3/18	.96	.47	.36	.27	.06	.04	.05	.02	.04	.03
3/22	.60	.30	.26	.17	.02	.02	.02	.01	.00	.00

Soil Moisture Accretion at Park

The predicted and actual accretions for all storms at Park site from October 1 to April 1 at the 6- to 9-, and 9- to 12-in. depths are shown in Table 15 and Figure 10.

The predicted values for Class I-W storms are those derived for summer conditions, shown in Table 10 of Appendix K in Progress Report I.

The deviations of predicted accretions from actual accretions are small, comparing favorably with those of summer, except for the storm of October 23. With this storm, the accretions for the different depths and tiers were quite variable and high, so that the average accretion to 12 in. exceeded rainfall. The results indicate a peculiar wetting of the units in the tiers rather than actual accretion in the soil profile. Excepting the storm of October 23, the average deviations of predicted from actual values in the 6- to 9-, and 9- to 12-in. depths are 0.01 and 0.01 in. compared to 0.02 and 0.01 in. for the summer.

For Class II storms at Park site, the relationships between available storage and accretion of summer storms did not hold for winter, primarily due to sparsity of summer data. A new prediction graph based on data of both summer and winter storms combining depths of 6 to 15 in. was derived (Figure 11). From this, predictions shown in Table 15 were determined. The deviations from the actual accretions are low and the average deviations compared favorably with those of summer based either on the summer or annual relation between available storage and accretion. The average deviations of predicted from actual values in the 6- to 9-, and 9- to 12-in. depths are respectively 0.02 and 0.01 in. for winter

Table 15

PREDICTED AND ACTUAL ACCRETIONS UNDER WINTER CONDITIONS, PARK SITE

Date of Storm	Rain-fall In.	Avail-able Storage 0-12 In.	Accretion 6 - 9 In. Pre-dicted	Actual	Devi-ation	Accretion 9 - 12 In. Pre-dicted	Actual	Devi-ation
			Class I-W Storms					
10/23/51	.73	1.76	.02	.12	-.10	.01	.23	-.22
10/31-11/1	.42	.73	.02	.00	.02	.01	.00	.01
11/6	.35	.66	.02	.01	.01	.01	.00	.01
11/14	.37	.56	.02	.01	.01	.01	.04	-.03
11/27	.53	.66	.02	.01	.01	.01	.01	.00
12/7A	.25	.27	.02	.01	.01	.01	.00	.01
12/14A	.25	.28	.02	.02	.00	.01	.01	.00
1/20/52	.29	.36	.02	.00	.02	.01	.00	.01
	Average deviation				.02			.04
	Summer deviation				.02			.01
			Class II Storms					
12/3	.80	.60	.10	.08	.02	.13	.10	.03
12/4-12/5	.40	.27	.03	.01	.02	.06	.04	.02
12/7P	1.07	.23	.03	.05	-.02	.05	.06	-.01
12/8-12/9	1.70	.09	.00	.00	.00	.01	.03	-.02
12/14P	.64	.20	.02	.00	.02	.01	.01	.00
12/17-12/18	.31	.22	.02	.01	.01	.02	.01	.01
12/19-12/20	.93	.27	.03	.01	.02	.01	.01	.00
1/4/52	.66	.42	.05	.05	.00	.03	.04	-.01
1/27	1.84	.40	.05	.06	-.01	.03	.07	-.04
2/1-2/2	1.16	.29	.03	.02	.01	.01	.02	-.01
2/12	.42	.38	.04	.02	.02	.01	.02	-.01
2/15-2/16	1.60	.28	.03	.01	.02	.00	.01	-.01
2/20	.30	.27	.04	.02	.02	.01	.02	-.01
2/22A	.73	.26	.03	.00	.03	.00	.01	-.01
2/25-2/26	.36	.24	.03	.00	.03	.01	.00	.01
3/3	.68	.37	.04	.02	.02	.01	.02	-.01
3/10	1.55	.43	.04	.02	.02	.01	.02	-.01
3/18	.69	.46	.05	.02	.03	.01	.02	-.01
3/22	.46	.33	.03	.02	.01	.01	.01	.00
	Average deviation				.02			.01
	Summer deviation (summer curve)				.01			.01
	Summer deviation (annual curve)				.03			.01

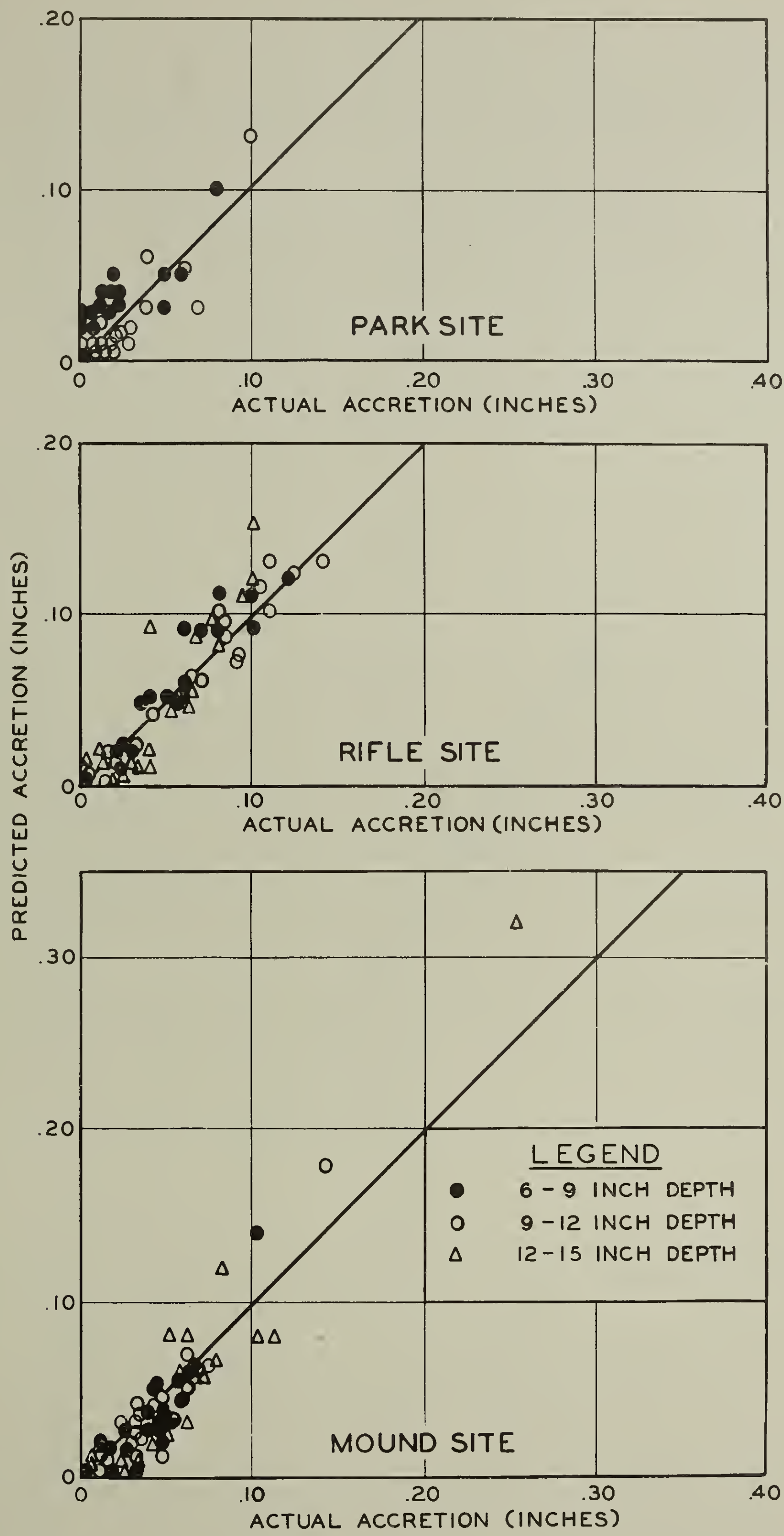

FIGURE 10. RELATION OF PREDICTED TO ACTUAL ACCRETION IN 6-15 INCH DEPTH. WINTER CLASS II STORMS.

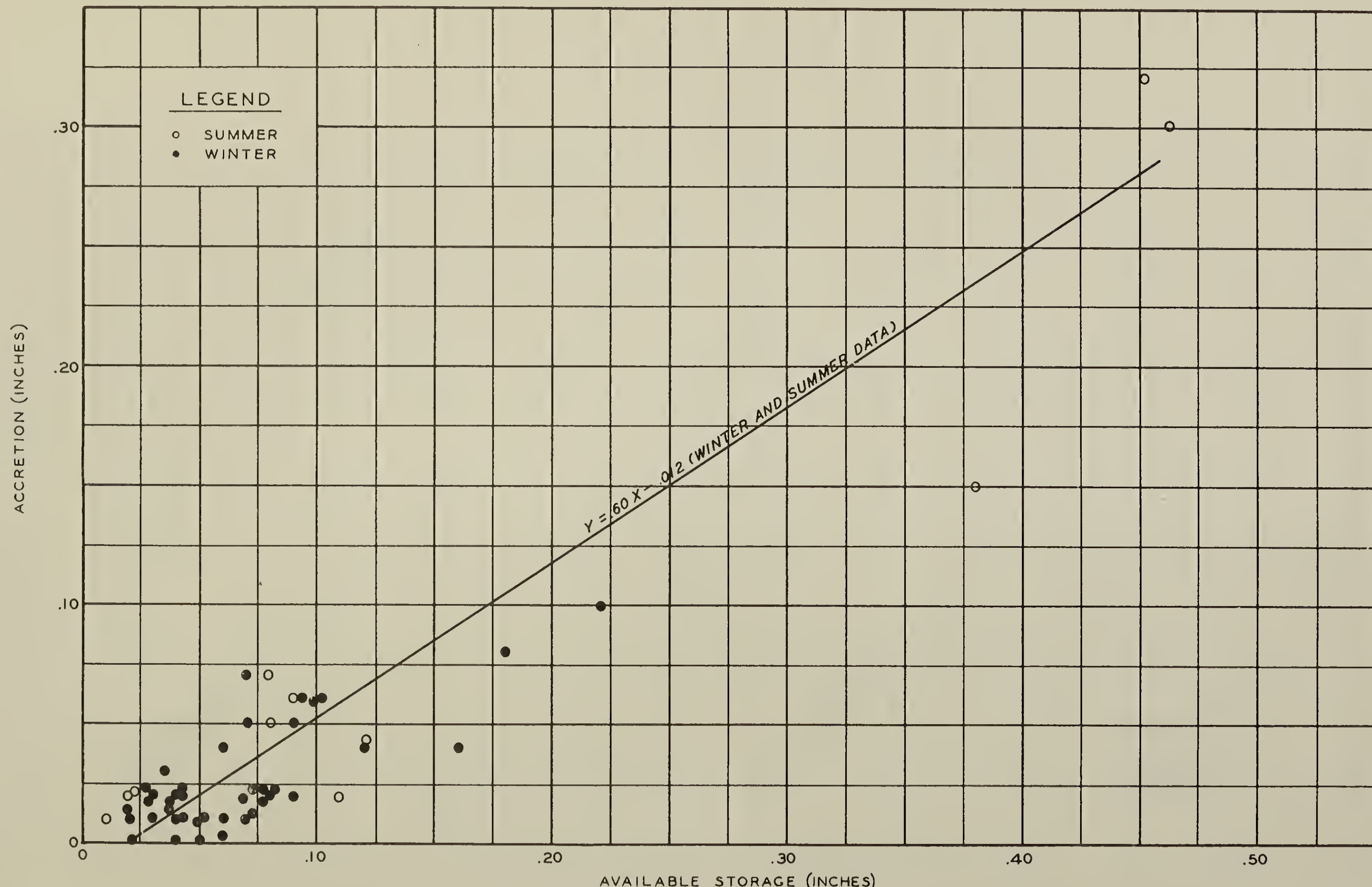

FIGURE 11. RELATION OF ACCRETION TO AVAILABLE STORAGE IN THE 6–15 INCH DEPTH

PARK SITE – CLASS II STORMS (DATA FROM ENTIRE YEAR)

storms, 0.01 and 0.01 in. for summer storms based on summer data, and 0.03 and 0.01 in. for summer storms based on annual data.

Soil Moisture Accretion at Rifle

The predicted and actual accretions of the 6- to 9-, 9- to 12-, and 12- to 15-in. depths for both Class I-W and Class II storms at Rifle are given in Table 16 and Figure 10.

The predicted values for Class I-W storms are those derived in the summer analysis as shown in Table 12 of Appendix K of Progress Report I. The average deviations are slightly greater in winter than in summer with values of 0.03, 0.05, and 0.04 in. for winter and 0.03, 0.03, and 0.02 in. for summer in the 6- to 9-, 9- to 12-, and 12- to 15-in. depths, respectively. Moisture accretion throughout the profile at Rifle site tended to be greater than rainfall as was true in summer. This condition can be attributed to surface runoff from the road and to recharge from high stream levels beyond the embankment following storms. Yet with this condition, the predictions were reasonably accurate in the 6- to 15-in. depth.

The predicted values for Class II storms were derived from the relation of accretion to storage given in Figure 12 for storms throughout the year. The predicted values agree with the actual. The average deviation during winter conditions is the same as in summer, 0.01, 0.01 and 0.02 in. for winter compared with 0.02, 0.02 and 0.00 in. for summer in the 6- to 9-, 9- to 12-, and 12- to 15-in. depths. The prediction graphs, Figure 12, based either on summer or annual data are in close agreement.

Table 16

PREDICTED AND ACTUAL ACCRETIONS UNDER WINTER CONDITIONS, RIFLE SITE

Date of Storm	Rainfall In.	Available Storage 0-12 In.	Accretion 6 - 9 In. Predicted	Accretion 6 - 9 In. Actual	Accretion 6 - 9 In. Deviation	Accretion 9 - 12 In. Predicted	Accretion 9 - 12 In. Actual	Accretion 9 - 12 In. Deviation	Accretion 12 - 15 In. Predicted	Accretion 12 - 15 In. Actual	Accretion 12 - 15 In. Deviation
					Class I-W Storms						
10/23/51	.84	2.04	.05	.05	.00	.06	.01	.05	.04	.00	.04
10/31	.44	1.28	.05	.02	.03	.06	.00	.06	.04	.00	.04
11/6	.47	1.09	.05	.05	.00	.06	.00	.06	.04	.00	.04
11/14	.45	.83	.05	.10	-.05	.06	.14	-.08	.04	.10	-.06
11/27	.49	.68	.05	.10	-.05	.06	.10	-.04	.04	.09	-.05
12/7 (A)	.30	.32	.05	.07	-.02	.06	.08	-.02	.04	.04	.00
12/14(A)	.36	.46	.05	.10	-.05	.06	.09	-.03	.04	.08	-.04
12/17	.29	.42	.05	.04	.01	.06	.10	-.04	.04	.08	-.04
1/20	.38	.46	.05	.10	-.05	.06	.12	-.06	.04	.10	-.06
	Average deviation				.03			.05			.04
	Summer deviation				.03			.03			.02
					Class II Storms						
12/3	.73	.54	.11	.08	.03	.13	.11	.02	.12	.10	.02
12/4	.32	.21	.01	.02	-.01	.02	.02	.00	.02	.01	.01
12/7(P)	.75	.07	.00	.00	.00	.00	.00	.00	.01	.00	.01
12/8-12/9	1.74	.20	.02	.02	.00	.01	.00	.01	.01	.02	-.01
12/14(P)	.45	.11	.00	.00	.00	.02	.03	-.01	.01	.03	-.02
12/19-12/20	.78	.36	.06	.06	.00	.07	.09	-.02	.05	.06	-.01
1/4/52	.60	.47	.12	.12	.00	.13	.14	-.01	.15	.10	.05
1/27	2.07	.51	.11	.10	.01	.12	.12	.00	.11	.10	.01
2/1	1.06	.38	.09	.08	.01	.09	.08	.01	.08	.08	.00
2/12	.47	.46	.09	.07	.02	.11	.10	.01	.09	.08	.01

(Continued)

Table 16 (Continued)

Date of Storm	Rain-fall In.	Avail-able Storage 0-12 In.	Accretion 6 - 9 In. Pre-dicted	Accretion 6 - 9 In. Actual	Accretion 6 - 9 In. Devi-ation	Accretion 9 - 12 In. Pre-dicted	Accretion 9 - 12 In. Actual	Accretion 9 - 12 In. Devi-ation	Accretion 12 - 15 In. Pre-dicted	Accretion 12 - 15 In. Actual	Accretion 12 - 15 In. Devi-ation
Class II Storms (Continued)											
2/15-2/16	1.70	.31	.05	.06	-.01	.07	.09	-.02	.05	.06	-.01
2/20	.35	.26	.05	.04	.01	.04	.04	.00	.01	.02	-.01
2/22	.70	.30	.05	.06	-.01	.06	.06	.00	.01	.04	-.03
2/25	.38	.15	.02	.03	-.01	.00	.01	-.01	.00	.01	-.01
3/3	.68	.34	.06	.04	.02	.08	.08	.00	.05	.06	-.01
3/9	.82	.46	.09	.10	-.01	.11	.10	.01	.09	.07	.02
3/10	.50	.14	.02	.02	.00	.01	.02	-.01	.01	.01	.00
3/17	.76	.45	.09	.06	.03	.10	.08	.02	.09	.04	.05
3/21	.77	.29	.05	.05	.00	.06	.07	-.01	.02	.04	-.02
	Average deviation				.01			.01			.02
	Summer deviation				.02			.02			.00

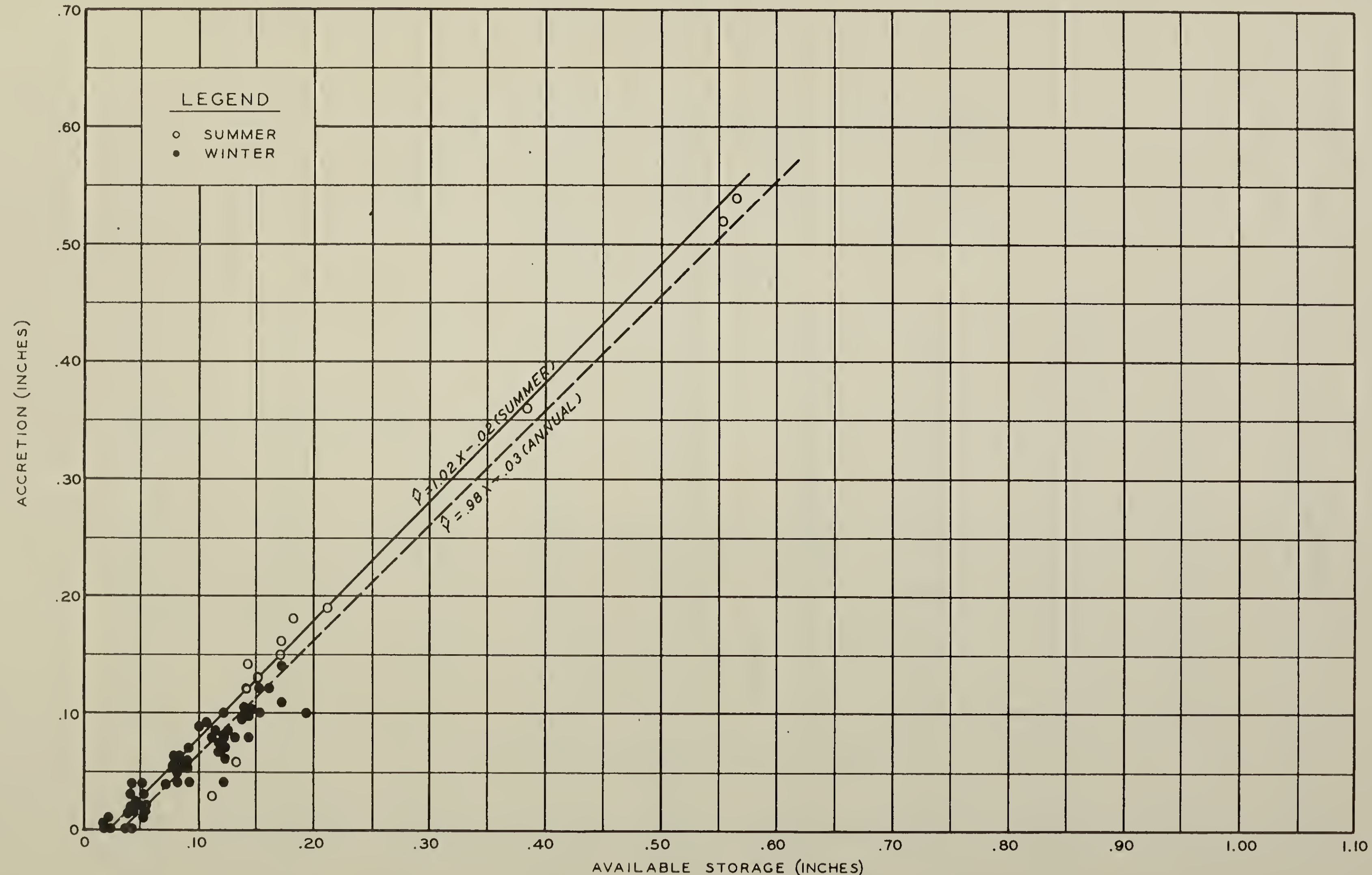

FIGURE 12. COMPARSION OF SUMMER AND WINTER ACCRETION BY SHOWING RELATION OF ACCRETION TO AVAILABLE STORAGE IN THE 6–15 INCH DEPTH

RIFLE SITE – CLASS II STORMS

Soil Moisture Accretion at Mound

The predicted and actual accretions at Mound for all storms are given in Table 17 and Figure 10. The predicted values of Class I-W storms are those derived for summer conditions shown in Table 13 of Appendix K in Progress Report I. The average deviations are small and compare favorably with those of summer predictions being 0.03, 0.01, and 0.02 in. in winter and 0.02, 0.02, and 0.03 in. in summer at the three depths. For Class II storms prediction is based on the relation of accretion to storage derived for annual storms given in Figure 13. Predicted and actual values are compared in Table 17. The average deviations are 0.01, 0.01, and 0.02 in. in winter and 0.02, 0.02, and 0.02 in. in summer at the three depths. The prediction graphs, Figure 13, derived for summer or annual data are about the same.

Comparison of Summer and Winter Accretions

Although soil moisture content is greater and available storage capacity is less in winter than in summer, nonetheless the relations used for accretion prediction in the winter are the same as in the summer. In the winter the soils remain wet and the available storage is therefore usually low prior to a storm. Since accretion is determined both by storm size and by the available storage, under winter conditions with the low storage a storm either slightly wets or fully satisfies available storage in the 6- to 15-in. depth, giving rise to two storm classes. The available storage is not great enough to result in a partial wetting of the 6- to 15-in. depth, the condition which existed in summer, giving

Table 17

PREDICTED AND ACTUAL ACCRETIONS UNDER WINTER CONDITIONS, MOUND SITE

Date of Storm	Rainfall In.	Available Storage 0-12 In.	Accretion 6 - 9 In. Predicted	Actual	Deviation	9 - 12 In. Predicted	Actual	Deviation	12 - 15 In. Predicted	Actual	Deviation
					Class I-W Storms						
10/31/51	.65	1.78	.03	.10	-.07	.03	.02	.01	.02	.02	.00
11/6	.27	1.23	.03	.00	.03	.03	.00	.03	.02	.00	.02
11/14	.63	1.18	.03	.06	-.03	.03	.03	.00	.02	.02	.00
11/27	.59	1.10	.03	.04	-.01	.03	.02	.01	.02	.00	.02
12/5	.29	.36	.03	.05	-.02	.03	.04	-.01	.02	.08	-.06
12/18	.30	.32	.03	.04	-.01	.03	.05	-.02	.02	.03	-.01
	Average deviation				.03			.01			.02
	Summer deviation				.02			.02			.03
					Class II Storms						
12/3	.89	.66	.14	.10	.04	.18	.14	.04	.32	.25	.07
12/6-12/7	1.40	.28	.05	.05	.00	.07	.06	.01	.12	.08	.04
12/9	2.06	.18	.01	.01	.00	.04	.03	.01	.06	.06	.00
12/13-12/14	.52	.32	.05	.04	.01	.05	.06	-.01	.08	.06	.02
12/19-12/20	.66	.26	.03	.03	.00	.04	.04	.00	.06	.07	-.01
1/4/52	.55	.47	.06	.06	.00	.06	.07	-.01	.08	.11	-.03
1/20	.32	.32	.05	.04	.01	.06	.07	-.01	.08	.05	.03
1/27	1.87	.45	.06	.06	.00	.06	.07	-.01	.08	.10	-.02
2/1	1.11	.30	.03	.04	-.01	.03	.04	-.01	.03	.06	-.03
2/12	.60	.46	.05	.06	-.01	.05	.05	.00	.06	.07	-.01

(Continued)

Table 17 (Continued)

Date of Storm	Rainfall In.	Available Storage 0-12 In.	Accretion 6 - 9 In. Predicted	Actual	Deviation	9 - 12 In. Predicted	Actual	Deviation	12 - 15 In. Predicted	Actual	Deviation
Class II Storms (Continued)											
2/15	.65	.25	.03	.04	-.01	.03	.03	.00	.03	.04	-.01
2/20	.32	.19	.02	.01	.01	.00	.00	.00	.00	.00	.00
2/22	.60	.22	.02	.03	-.01	.00	.02	-.02	.00	.01	-.01
2/25	.39	.03	.00	.00	.00	.00	.00	.00	.00	.00	.00
3/3	.60	.31	.03	.05	-.02	.01	.03	-.02	.00	.02	-.02
3/10A	.87	.46	.03	.04	-.01	.03	.03	.00	.02	.03	-.01
3/10P	.98	.12	.00	.01	-.01	.00	.01	-.01	.00	.01	-.01
3/18	.96	.47	.03	.04	-.01	.03	.02	.01	.02	.03	-.01
3/22	.60	.30	.00	.02	-.02	.00	.01	-.01	.00	.00	.00
	Average deviation				.01			.01			.02
	Summer deviation				.02			.02			.02

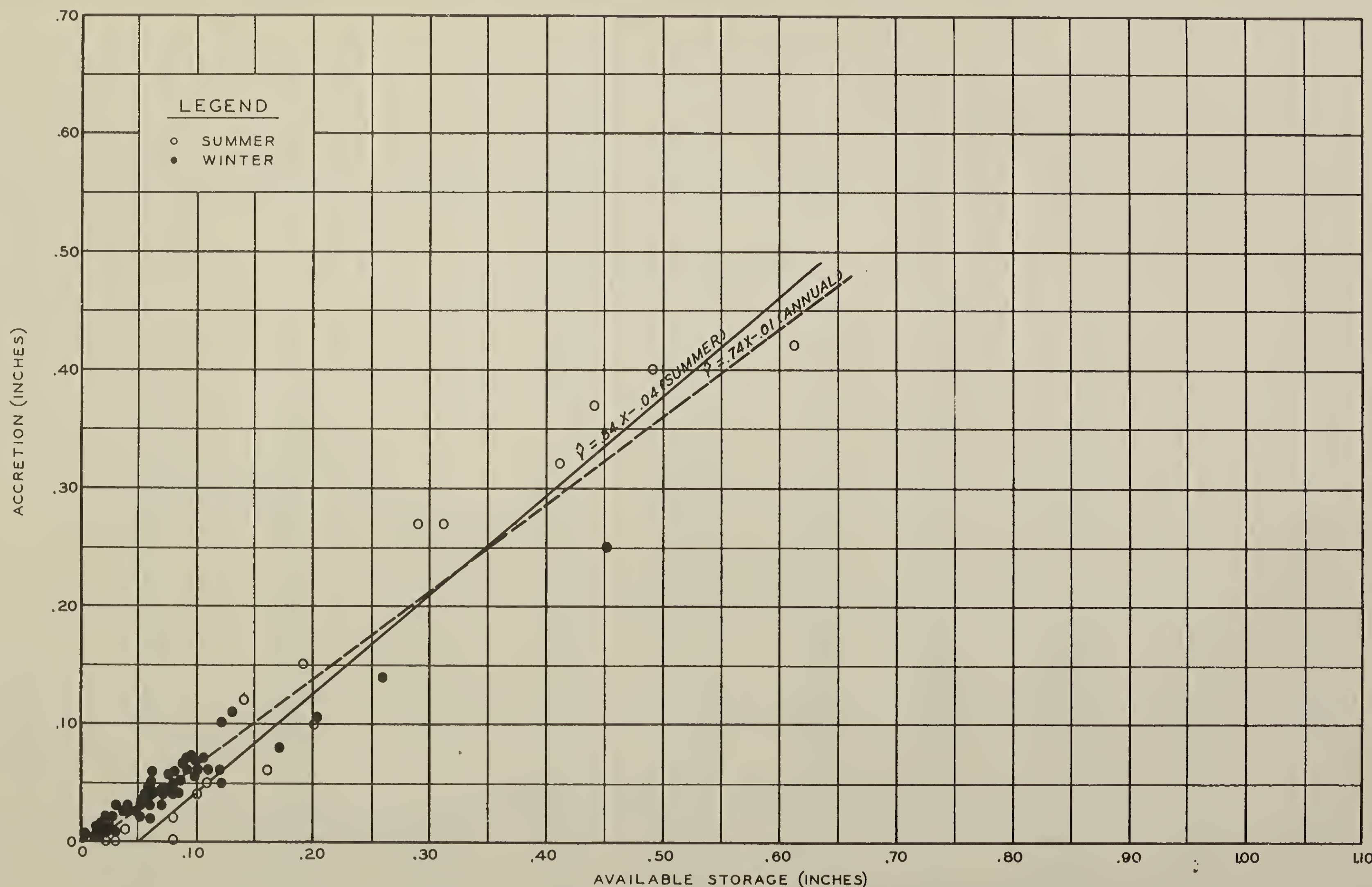

FIGURE 13. COMPARSION OF SUMMER AND WINTER ACCRETION BY SHOWING RELATION OF ACCRETION TO AVAILABLE STORAGE IN THE 6-15 INCH DEPTH

MOUND SITE - CLASS II STORMS

rise to the Class III storm category.

Except for the change in storm classification, accretion and accretion prediction have the same relations with storm size and available storage for both summer and winter storms, so that the same prediction relations can be used for all seasons.

With Class I storms, the soils are only slightly wetted in the 6- to 15-in. depth, so the average accretion following storms in this category is used as a basis for accretion prediction. Table 18 compares the winter and summer average accretions at the three sites.

Table 18

COMPARISON OF WINTER AND SUMMER AVERAGE ACCRETIONS FOLLOWING CLASS I STORMS

Soil Depth (In.)	Season	Average Accretion (In.) Park	Rifle	Mound
6-9	Winter	.01*	.07	.05
	Summer	.02	.05	.03
	Annual	.02*	.06	.04
9-12	Winter	.01*	.07	.03
	Summer	.01	.06	.03
	Annual	.01*	.06	.03
12-15	Winter	-	.06	.02
	Summer	.00	.04	.02
	Annual		.05	.02

* Storm of 10/23 not included.

The close agreement between summer and winter average accretions is apparent. For the prediction of accretion of Class I storms, a single relation holds throughout the year.

Likewise with Class II storms, a single relation exists for summer

and winter. As shown in Figures 11, 12, and 13 for the three sites, accretion has a linear relationship with available storage irrespective of season. The difference in soil conditions during winter compared with summer is shown by the smaller available storage and consequently smaller accretions during winter.

PREDICTION OF SOIL MOISTURE ACCRETION FROM WATER TABLE LEVELS

The prediction of soil moisture accretion in Progress Report I for the period April 1 to October 1, 1951 was based entirely on the effect of precipitation. During most of this period the water table was too low to have any effect on soil moisture content at the prediction depths. During the subsequent 6 months, however, the combination of increased rainfall and reduced evapo-transpiration losses raised the level of the water table at alluvial sites to a point where the moisture contents at the prediction depths were affected. For part of this period there were two sources of moisture, precipitation falling on the soil and moving downward, and the water below the surface moving upward from the water table. The purpose of this section is to describe the effect of water table on soil moisture content, first on a theoretical basis, and then in relation to data from the prediction sites.

When soil moisture content is affected only by the water table, the moisture content at any one depth depends on its distance above the water level. Theoretically, the height above water table is equivalent in turn, to the soil moisture tension at that depth. As Richards (3)* has stated:

> "Expressed in equivalent length of water columns, the maximum tension that can be developed at any given point in field soil by downward drainage is equal to the elevation of the point above the water table."

The tension-height of water table relation holds, regardless of soil

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* Numbers in parentheses refer to references listed at the end of this section.

texture, being equal for sands, silts, or clays. This is indicated at low tensions in Figure 14, from work by Moore (2). In this laboratory study evaporation from the surface was quite rapid, hence tensions at the various depths are not necessarily equal to the height above the water table, particularly at high tensions where the water table is several feet below the surface. However, the similarity in shape and position of the curves and, in particular, the near equivalence between tension and height above water table for the lower tension, point up the validity of Richard's theory.

Since tension is also related to moisture content, it is obvious that with the tension-height of water table relation plus information on the tension-moisture content relation for the soil observed, the moisture content-height of water table relation may be determined. As will be shown, these interrelationships have been used to predict moisture content based on depth to water table.

These interrelationships, however, hold only for periods when the water table is fairly close to the soil surface. Theoretically, when the water table is at a depth of approximately 300 centimeters (about 1/3 of an atmosphere) or 10 ft from the surface, the soil surface should have a moisture content of about field capacity. This does not occur under natural conditions. Moisture content is normally above or below field capacity for any one of the three following reasons:

a. During summer periods of high rate of evapo-transpiration, water is removed more rapidly than it can be supplied from the water table. Even under winter conditions, evaporation from the upper few inches of soil reduces moisture content below field capacity.

b. Rainfall upsets this relation, adding to the soil more

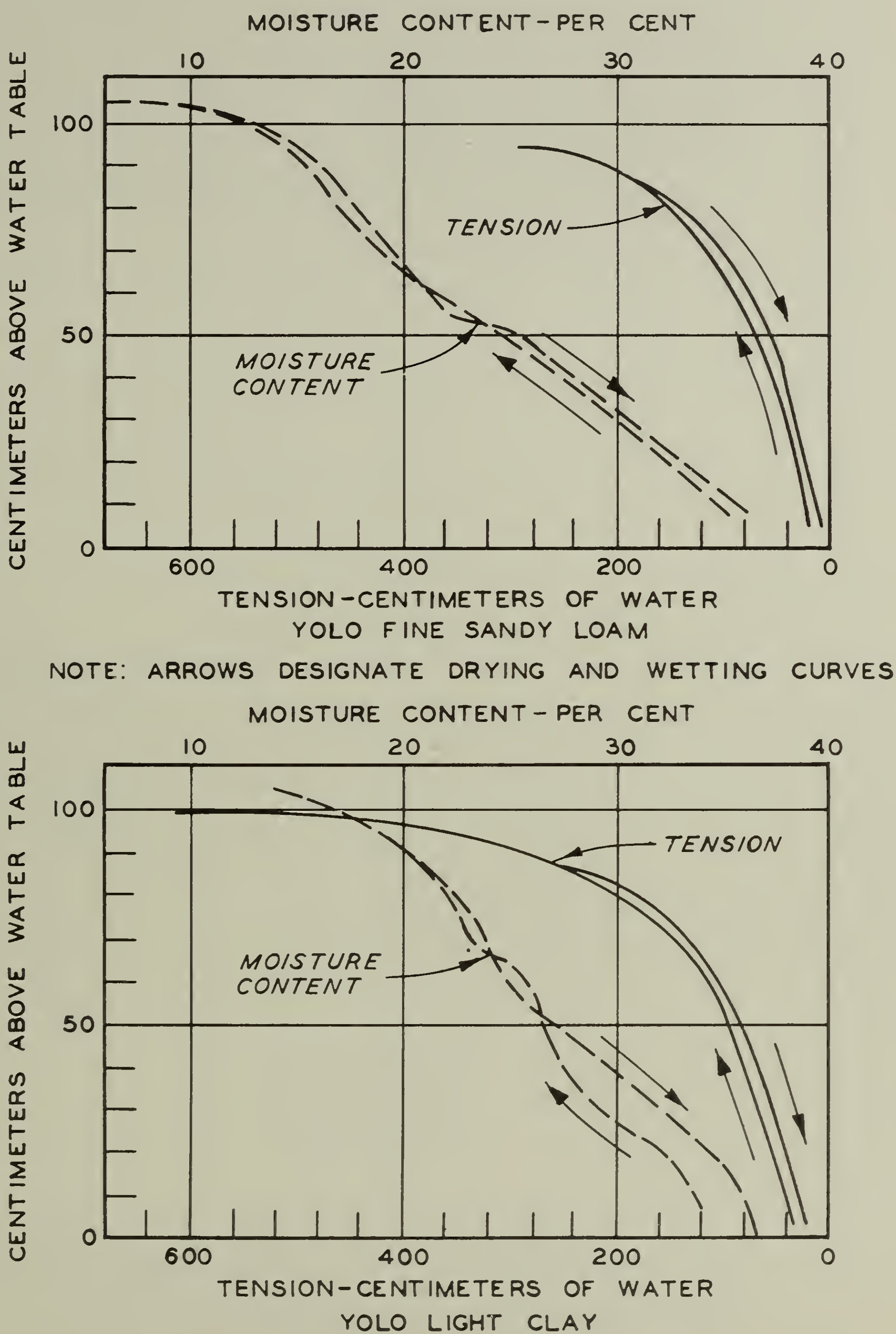

FIG. 14. RELATION OF TENSION AND MOISTURE CONTENT TO HEIGHT ABOVE WATER TABLE FOR TWO CALIFORNIA SOILS (AFTER MOORE).

moisture (in terms of tension) than could be furnished by the water table.

c. Finally, rate of upward movement of water is so slow that rarely does sufficient time elapse between rainfalls or drying periods for the soil moisture and tension to come into the equilibrium dependent on distance from the water table.

Thus, based on tension theory, there is a distinct relation of tension (and therefore moisture content) to water table levels. Based on rate of soil moisture movement upward from the water table, this theory departs from the actual for lack of time required to reach equilibrium. For this reason, the water table will affect soil moisture content for only a limited distance, and this distance is based primarily on textural characteristics that affect rate of movement. For instance, Keen (1) found that when free water surface was at 35 cm in sand, 70 cm in fine sand, and 85 cm in clay soil with flints, its power of supplying water to upper limits was negligible. He stated that in heavy soil capillary movement can only be effective for 3 ft.

Based on the effect of rainfall, evapo-transpiration, and slow water movement from the water table, the relation of moisture content to depth above water table falls into one of the three following categories:

a. A state of equilibrium when the moisture content is a function of height above the water table and the moisture-tension characteristics of the soil. This is the ideal state which would be established in time if not upset by rain or other external factors.

b. The state in which the soil above the water table has been wetted from above and, equilibrium not having been established, the moisture content is higher than would be the case in a state of equilibrium. This condition exists through part of the soil mantle after every rainfall.

c. The state existing when evaporation or transpiration removes water from the soil at a rate faster than it can be replenished from the water table, resulting in moisture contents lower than would be the case under equilibrium conditions. This situation is prevalent on vegetated areas during the growing season except for short periods after rains.

A prediction of soil moisture content from the depth to water table is possible for category a when equilibrium conditions have been reached. This method can also be used to predict minimum values for moisture content during wet periods of category b. Under conditions of category c no prediction of moisture content from water table data can be made.

Available Data and Analysis

At the alluvial sites, Rifle and Mound, observation wells were maintained and a daily record of water level kept. A daily record of soil moisture content at various depths was available from the Fiberglas soil moisture unit installations. For Rifle and Mound, moisture-tension curves for the 9- to 12-in. soil depth were developed from laboratory determinations.

To predict moisture content on basis of water table level, theoretical curves were prepared showing depth of soil moisture in inches against height above water table (Figure 15). To accomplish this for the 9- to 12-in. depth, soil moisture contents and equivalent tensions were read from the laboratory curves for tensions ranging from zero to nine ft of water (equivalent to 0-270 cm or 0-0.27 atmos). Each moisture content value was then plotted against the height above water table equivalent to its tension in height of water column. For example, for the 9- to 12-in. depth at Rifle, the moisture content at two feet (approximately

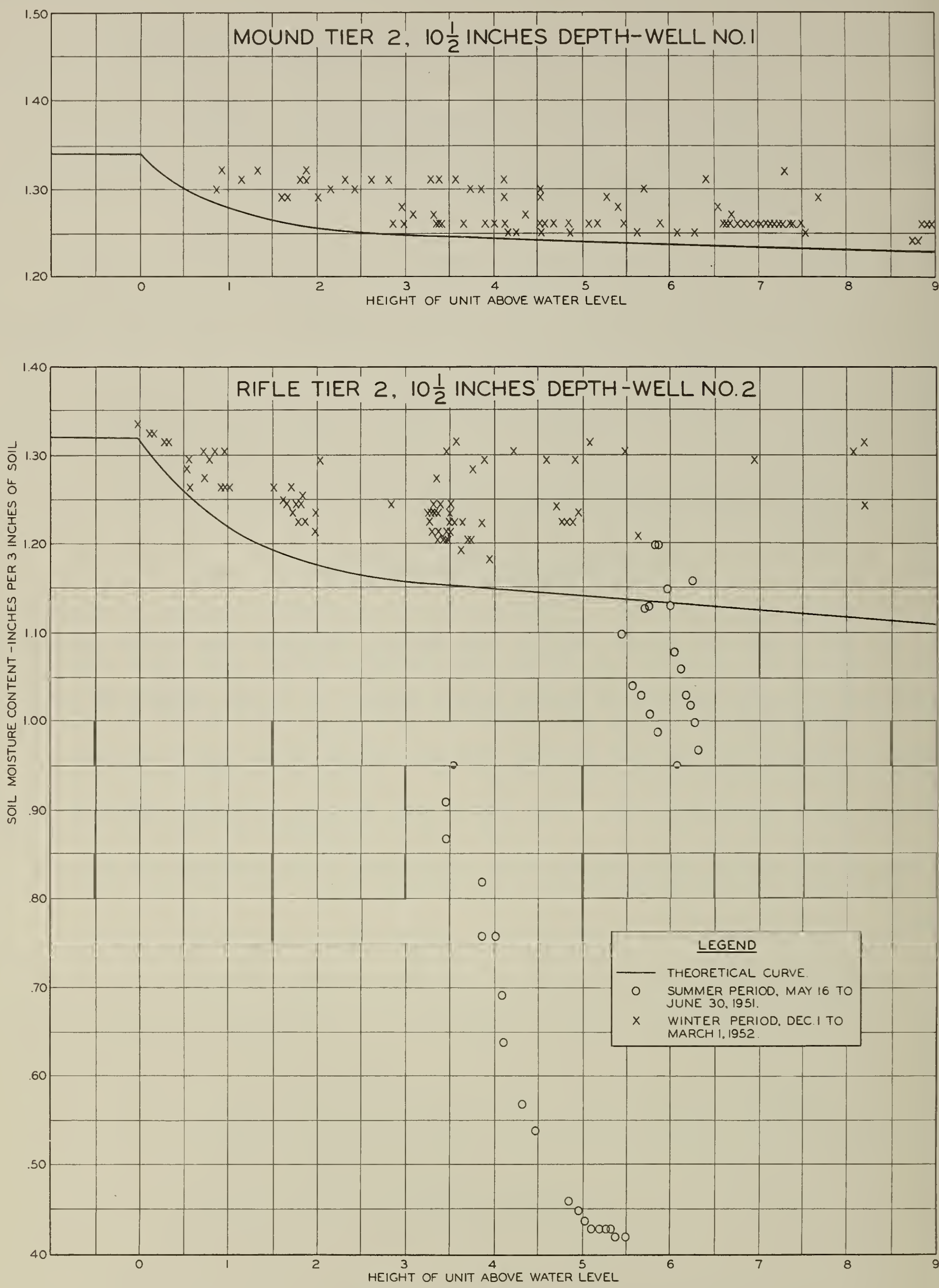

FIGURE 15. RELATION BETWEEN SOIL MOISTURE CONTENT AND HEIGHT ABOVE WATER TABLE.

61 cm) of tension is 26.8 per cent or, converted to volume, 1.18 in. This value was then plotted over the 2-ft height above water table. Several points determined in this manner were connected to form a curve. The curve represents the moisture content expected with the establishment of equilibrium conditions.

On the same graphs, soil moisture content as determined with the Fiberglas unit for each day of the period from December 1, 1951 to February 29, 1952 was plotted against the height above water level of that point on that day.

It will be noted that almost all of the points fall above the equilibrium curve. The winter climate at Vicksburg is characterized by frequent rains; the winter of 1951-52 was no exception. Also at this time evapo-transpiration is at a minimum. Consequently the soil is generally wetter than would be the case if equilibrium with the water table were reached (category b described above). Taking Mound, Figure 15 as an example, for the 68 per cent of the days of record, moisture content is greater than equilibrium. However, for prediction purposes, the curves in Figure 15 do define during winter conditions minimum levels of soil moisture content between storms. This agrees with Richards' statement that:

> ".... at a given height above the water table after a soaking rain, downward drainage cannot reduce the moisture content of a soil below the value...at the tension corresponding to this height."

A few points fall below the equilibrium curve. In these cases the water level in the well may not have reached equilibrium with the water table or the height of the water table may vary somewhat even in the short

distance between the observation well and the soil moisture unit location. Also, the moisture-tension relation for the location where soil samples for laboratory testing were obtained may vary from the relation at the soil moisture unit location. Again, evaporation and even limited transpiration could reduce the moisture content below that which would exist in a state of equilibrium.

The soils at Rifle and Mound show very little change in moisture content for the heights of water table found during the winter season, owing to the small range of moisture content at tensions equivalent to the height above water table as shown in Progress Report I. Therefore, the prediction would necessarily cover only a narrow range of moisture content. This, however, does not hold for all soils -- some soils yield much more water for a given amount of increase in tension than do other soils. Figure 16, based upon moisture-tension curves in Progress Report I, shows the relation of moisture per cent at equilibrium to height above water table for Rifle and Mound soils and for certain California soils tested by Richards and Weaver (4). Predictions based on height above water table for these California soils would cover a much wider range of moisture content.

Figure 17 shows for Durden Creek* the relation between soil moisture per cent at the 7-1/2-in. depth and water level in the observation well on the same day. The data necessary for determining moisture content in inches depth and the moisture-tension relation have not yet been obtained

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* Durden Creek is a new site recently brought under study at the request of the Waterways Experiment Station. The soil is colluvial low land, Briensburg silt loam, with moderately slow internal drainage. Vegetation on the site is herbaceous.

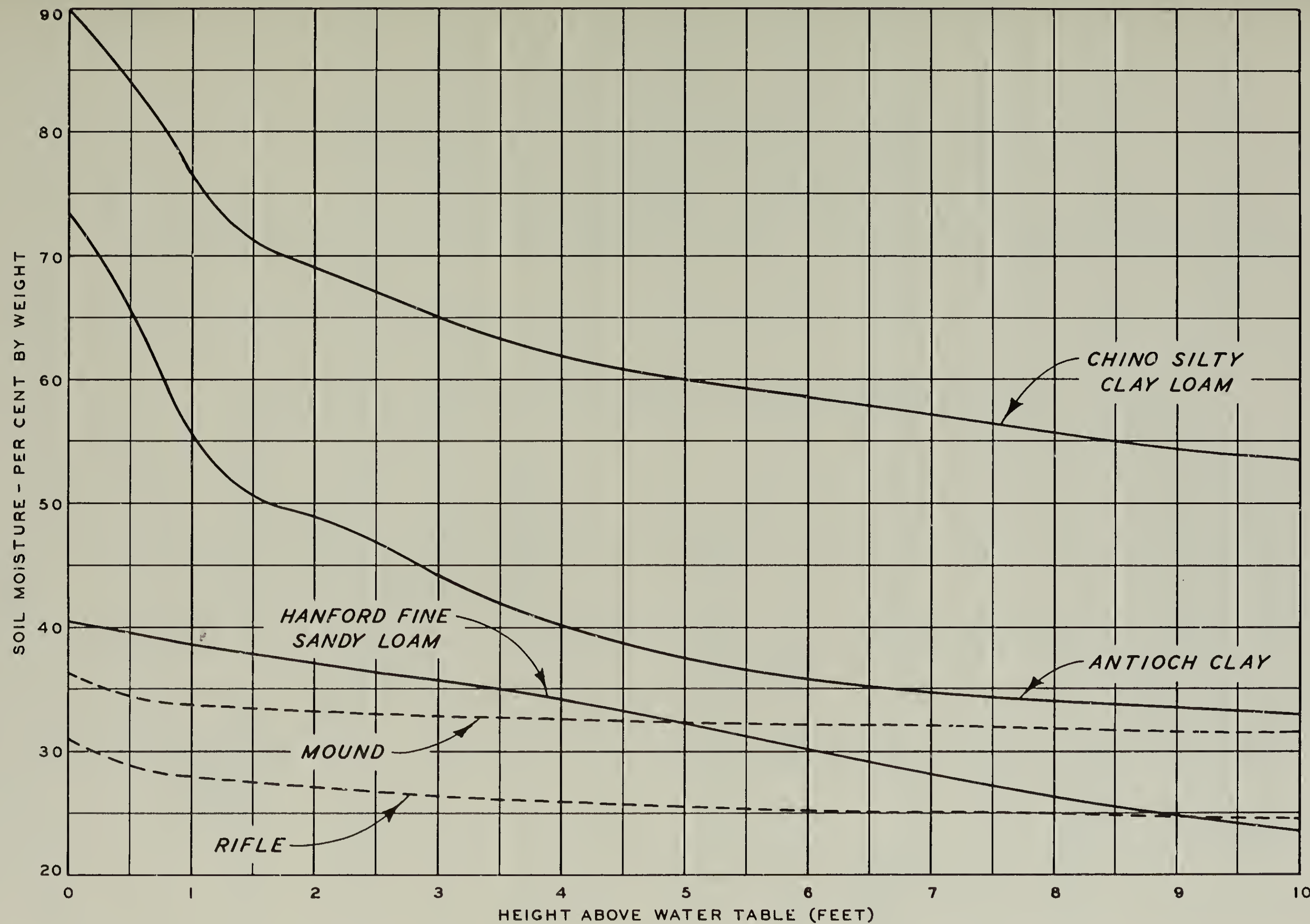

FIGURE 16. RELATION BETWEEN SOIL MOISTURE CONTENT AND HEIGHT ABOVE WATER TABLE FOR RIFLE AND MOUND SOILS ($10\frac{1}{2}$ INCHES DEPTH) COMPARED TO CALIFORNIA SOILS TESTED BY RICHARDS AND WEAVER

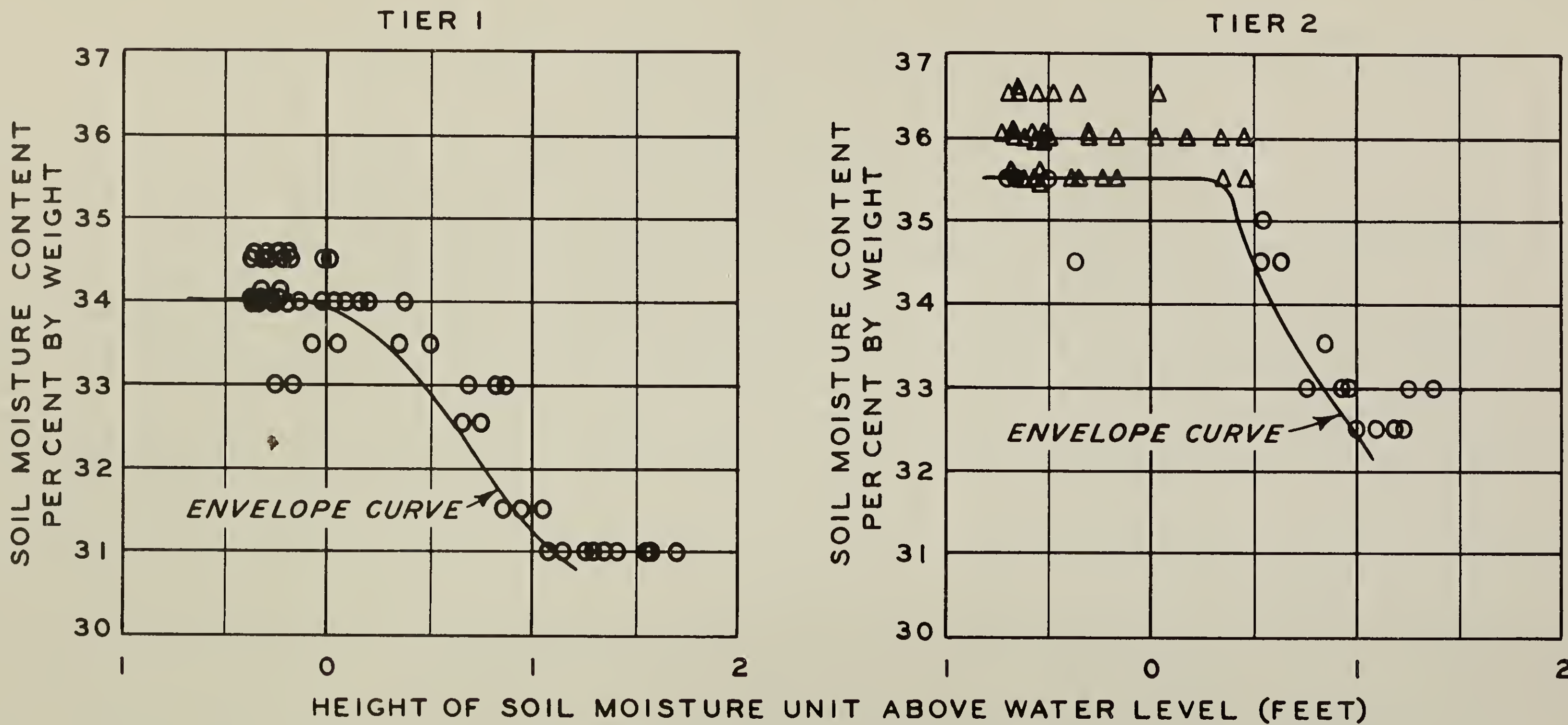

FIGURE 17. RELATION BETWEEN SOIL MOISTURE CONTENT AND HEIGHT ABOVE WATER TABLE
DURDEN SITE - $7\frac{1}{2}$ INCHES SOIL DEPTH

for this site. There was very little fluctuation in the water table at Durden during the period of record. An envelope curve was drawn on these graphs for which practically all of the points fell on or above the curve. This envelope curve can be used to predict, for periods having conditions similar to the period of record, a minimum level of moisture content for a given height of the water table.

The above figures and discussion concern conditions at the alluvial sites during the winter season which fall into categories a and b. Figure 15 also illustrates conditions of category c in that it shows the relation between moisture content and height above water table at Rifle during part of the summer season. It is evident that soil moisture depletion, largely transpiration by rapidly growing vegetation, has lowered the moisture level far below that expected if a state of equilibrium with the water table existed.

Conclusions

Theoretically, the effect of the water table on soil moisture content can be predicted utilizing the tension-distance from water table relation and the tension-moisture content curves.

For periods of frequent rainfall and low evapo-transpiration rates, such as the winter season at Vicksburg, these criteria can be used to predict a minimum level of moisture content, because under these conditions the moisture content will be at or above the equilibrium value.

If moisture-tension curves are not available, envelope curves prepared from moisture content and water table data for a period of record can be used to predict the minimum level of moisture content.

Literature Cited

1. Keen, Bernard A.,
   1931. The physical properties of the soil. p 93. London, New York, Toronto.

2. Moore, Ross E.,
   1939. Water conduction from shallow water tables. Hilgardia, 12 (6): 383-426.

3. Richards, L. A.,
   1941. Uptake and retention of water by soil as determined by distance to a water table. Journal of the American Society of Agronomy, 33: 778-786.

4. Richards, L. A., and Weaver, L. R.,
   1944. Moisture retention by some irrigated soils as related to soil moisture-tension. Jour. of Ag. Research, 69:215.

SOIL MOISTURE DEPLETION

Soil moisture depletion during the six-month period of record was influenced by seasonal changes in climate and vegetation. Summer conditions of drying prevailed through the month of October. The next four months, November through February, constituting the real "winter" period of low temperatures, frequent rainfall, and dormant vegetation, were marked by low rates of depletion. In late February and March higher air temperature and regrowth of vegetation increased depletion rates to a point about midway between the winter and summer rates.

Depletion curves for the winter season were prepared in much the same manner as those for the summer as described in Appendix L, Progress Report I. Daily moisture contents for periods of depletion were plotted as shown, for example, in Figure 18, by matching days of similar moisture content and depletion rate. Within such families of curves, the average depletion curves were drawn.

Winter Depletion

Park

Twelve depletion periods were studied at Park: 10/3-23; 10/24-31; 11/14-26; 11/27-12/3; 12/20-29; 1/4-14; 1/20-25; 2/5-11; 2/26-3/1; 3/4-9; 3/13-17; and 3/22-31.

The first two periods, coming before the first killing frost, were more nearly typical of summer conditions than of winter conditions, and so were not considered in arriving at the average winter depletion curves. Depletion during the four periods after mid-February also occurred at a

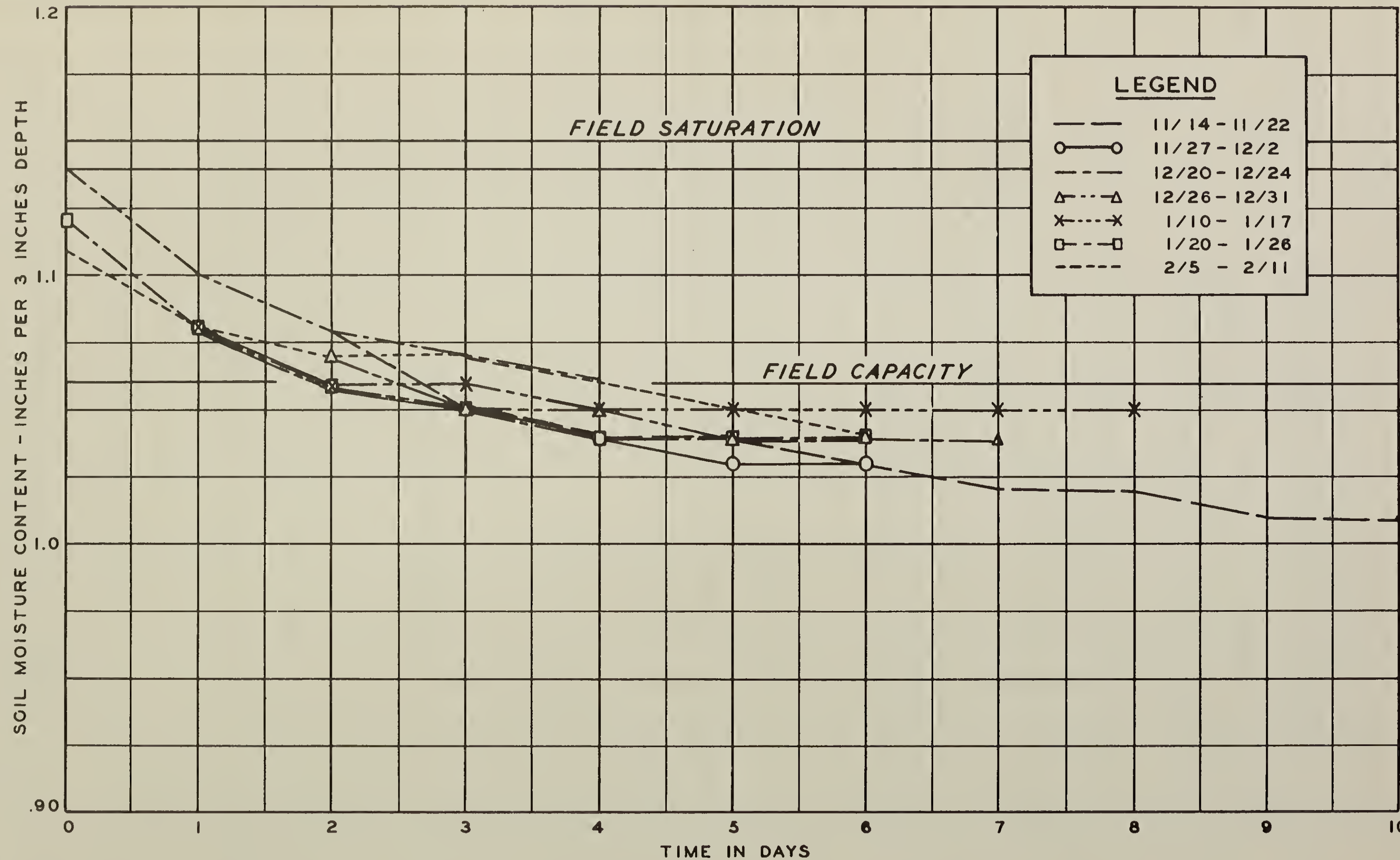

FIGURE 18. DEPLETION CURVES FOR WINTER DRYING PERIODS AT RIFLE SITE, 3 TO 6 INCHES DEPTH

faster rate than in winter, and was therefore treated separately.

Average winter depletion curves were prepared on the basis of the six depletion periods between November 14 and February 11 (Figure 19).

Rifle

At Rifle, twelve depletion periods were studied. The dates correspond roughly to those used at Park.

Here again, when preparing the average winter depletion curves, the periods in October and after mid-February were excluded as not typical of winter conditions. The average winter depletion curves are shown in Figure 20.

Mound

At Mound, thirteen depletion periods were examined, twelve generally corresponding in dates to those at Park, plus the period of November 6 to 10. The average depletion curves, covering the period of November 6 to January 26, are shown in Figure 21.

Winter, Summer, and Spring Depletion

The average depletion curves of the three sites can be separated into two phases. In the first, depletion is rapid due to gravity drainage of water from saturation to field capacity. This takes two to three days. The second phase starts at about field capacity and is characterized by a marked reduction in depletion rates. Here depletion can be attributed principally to evaporation. In this phase, rates diminish with depth reflecting the reduced effects of evaporation in the lower layers.

A comparison of the summer and winter average depletion curves

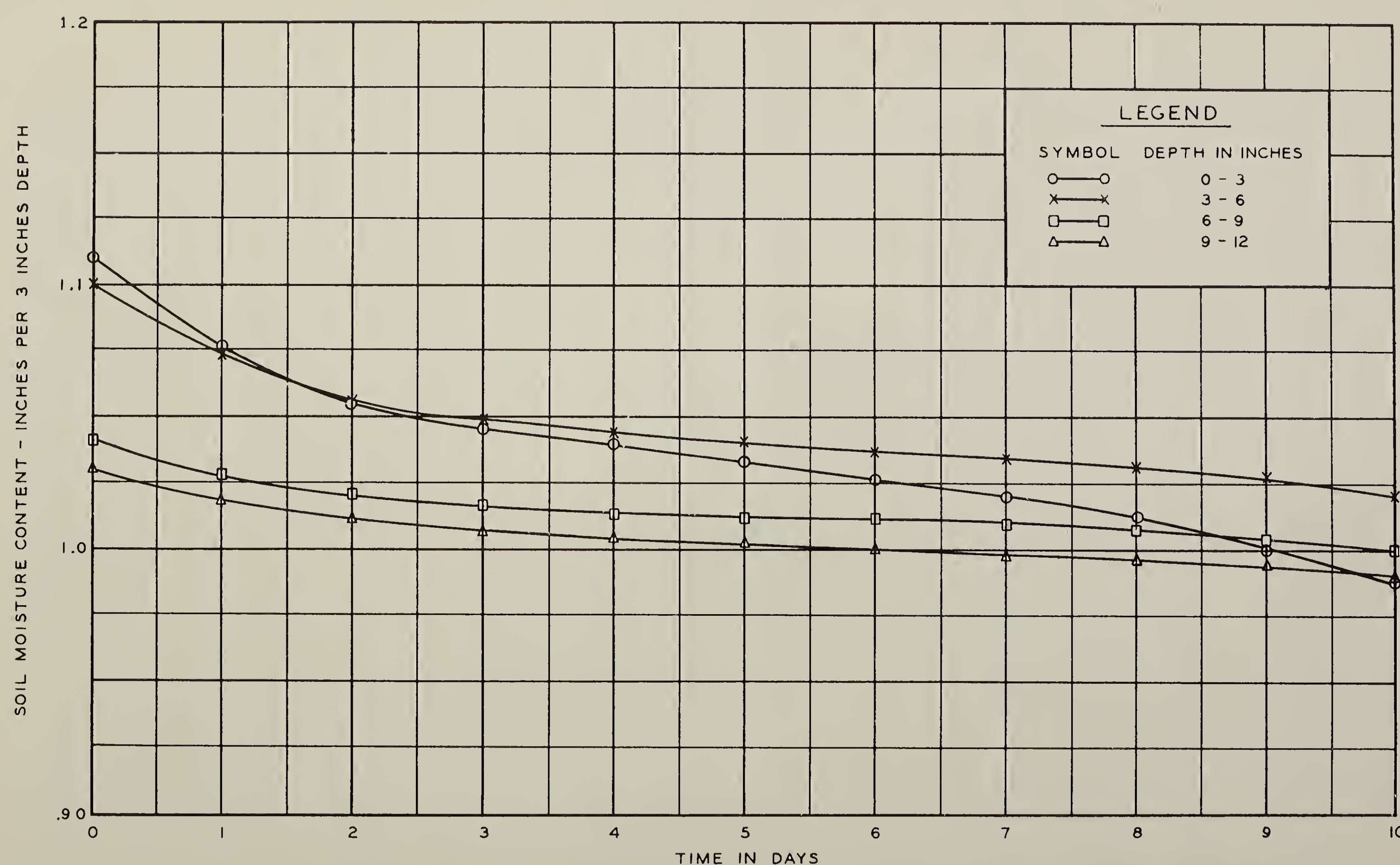

FIGURE 19. AVERAGE SOIL MOISTURE DEPLETION CURVES FOR PARK SITE

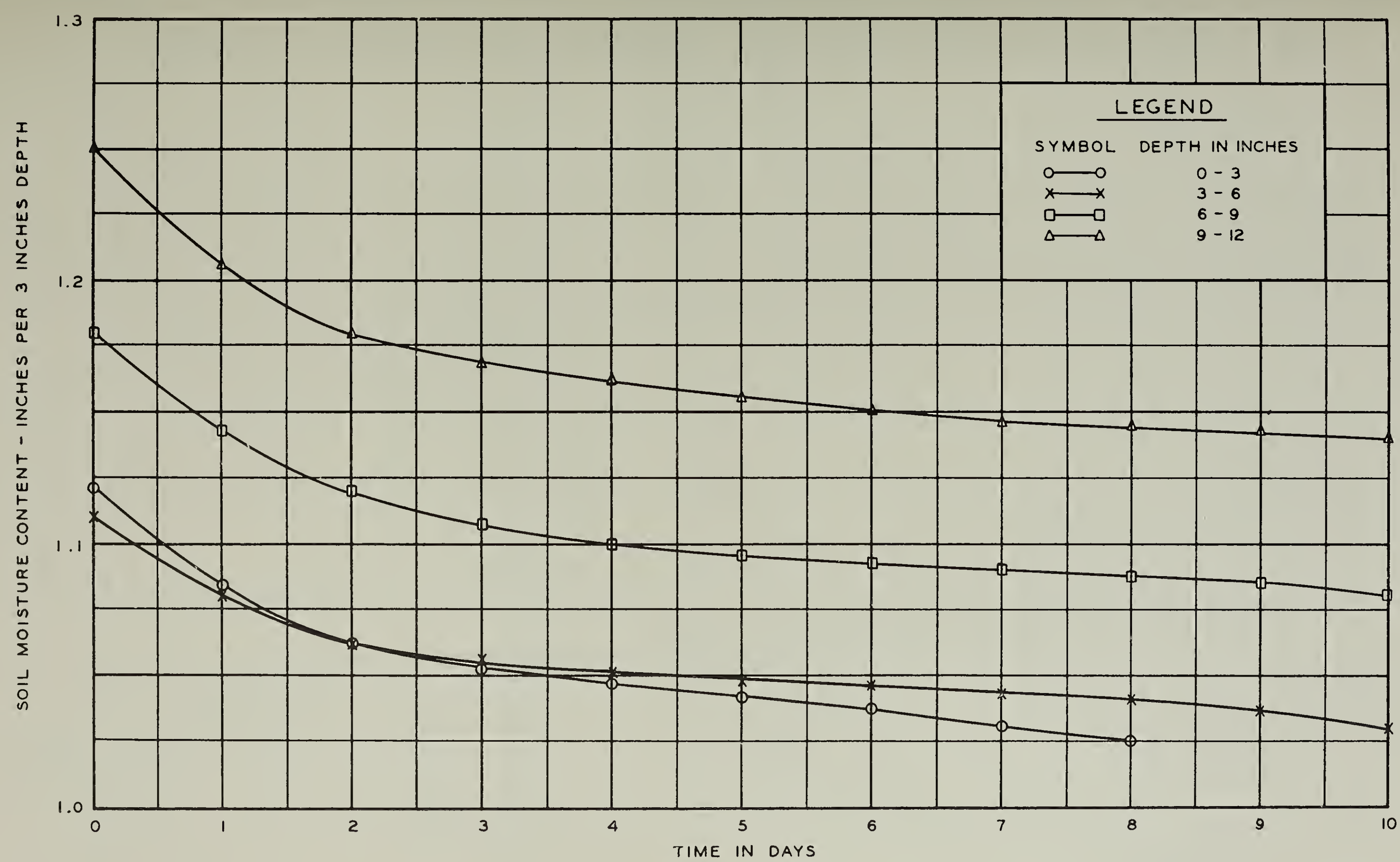

FIGURE 20. AVERAGE SOIL MOISTURE DEPLETION CURVES FOR RIFLE SITE

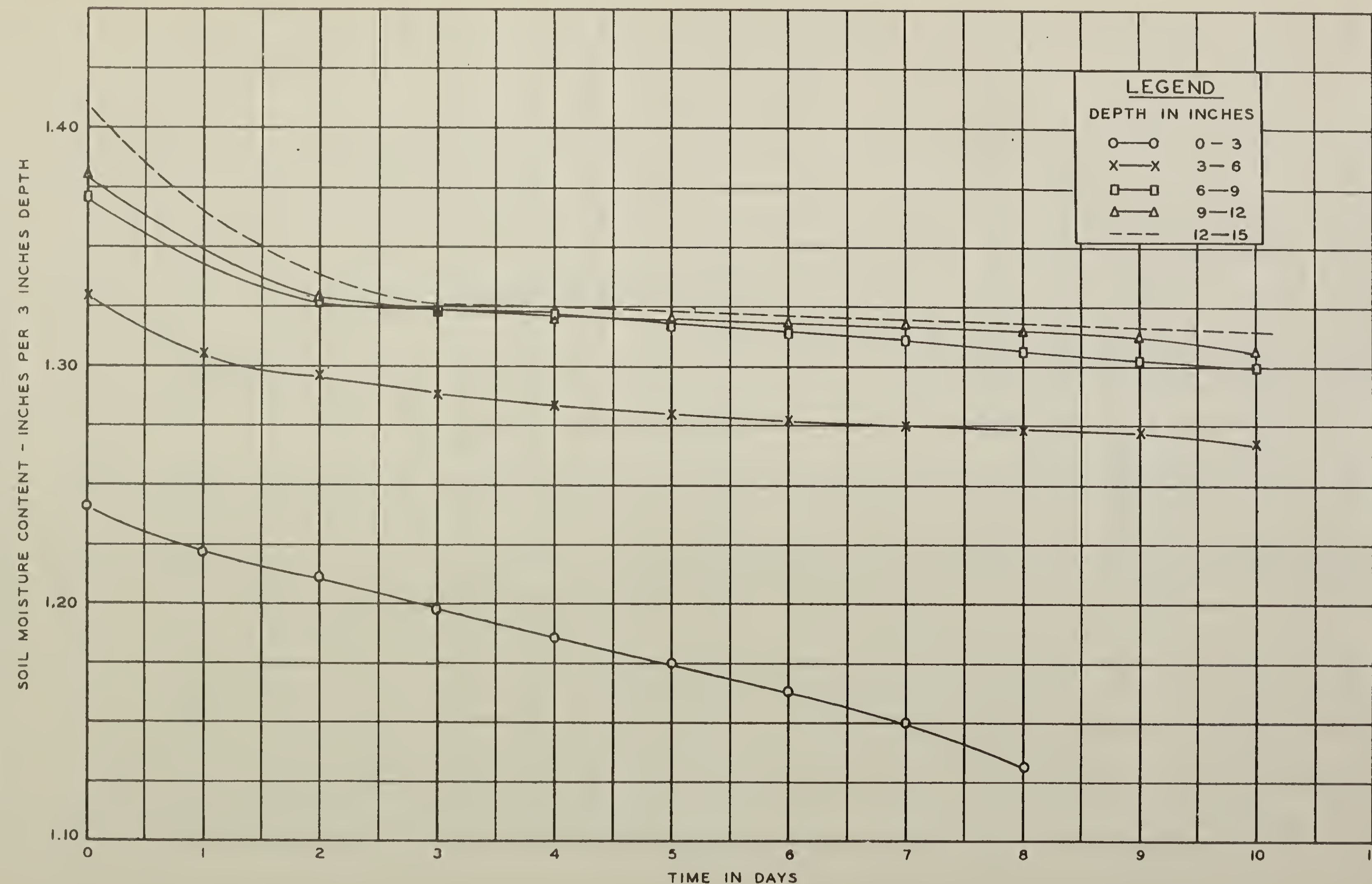

FIGURE 21. AVERAGE SOIL MOISTURE DEPLETION CURVES FOR MOUND SITE

(Figure 22), shows a nearly parallel drop due to gravity drainage for about the first two days and then a marked difference in the rate of depletion, with the summer curves showing a continued drop and the winter curves showing a marked leveling-out effect after the disappearance of gravity water.

Average daily rates of moisture loss at moisture contents less than field capacity for both summer and winter are given in Table 19. Depletion in summer, influenced largely by transpiration, was about 10 times greater for all depths at Park and Rifle than in winter. The difference in winter and summer rates at Mound for the surface 3 in. was of the same magnitude, but at greater depths it was about 20 times greater in summer than in winter. The slower loss in winter at Mound below the 0-3-in. layer indicates the effective depth of winter evaporation for clay soils of this nature.

Table 19

AVERAGE DAILY SOIL WATER LOSS FOLLOWING FIELD CAPACITY LEVEL AT PARK, RIFLE AND MOUND FOR SUMMER AND WINTER PERIODS

Location	Soil Depth, In.	Soil Water Loss, In. Summer	Soil Water Loss, In. Winter
Park	0-3	.044	.003
	3-6	.022	.002
	6-9	.018	.001
	9-12	.012	.001
Rifle	0-3	.035	.003
	3-6	.022	.003
	6-9	.019	.002
	9-12	.020	.002

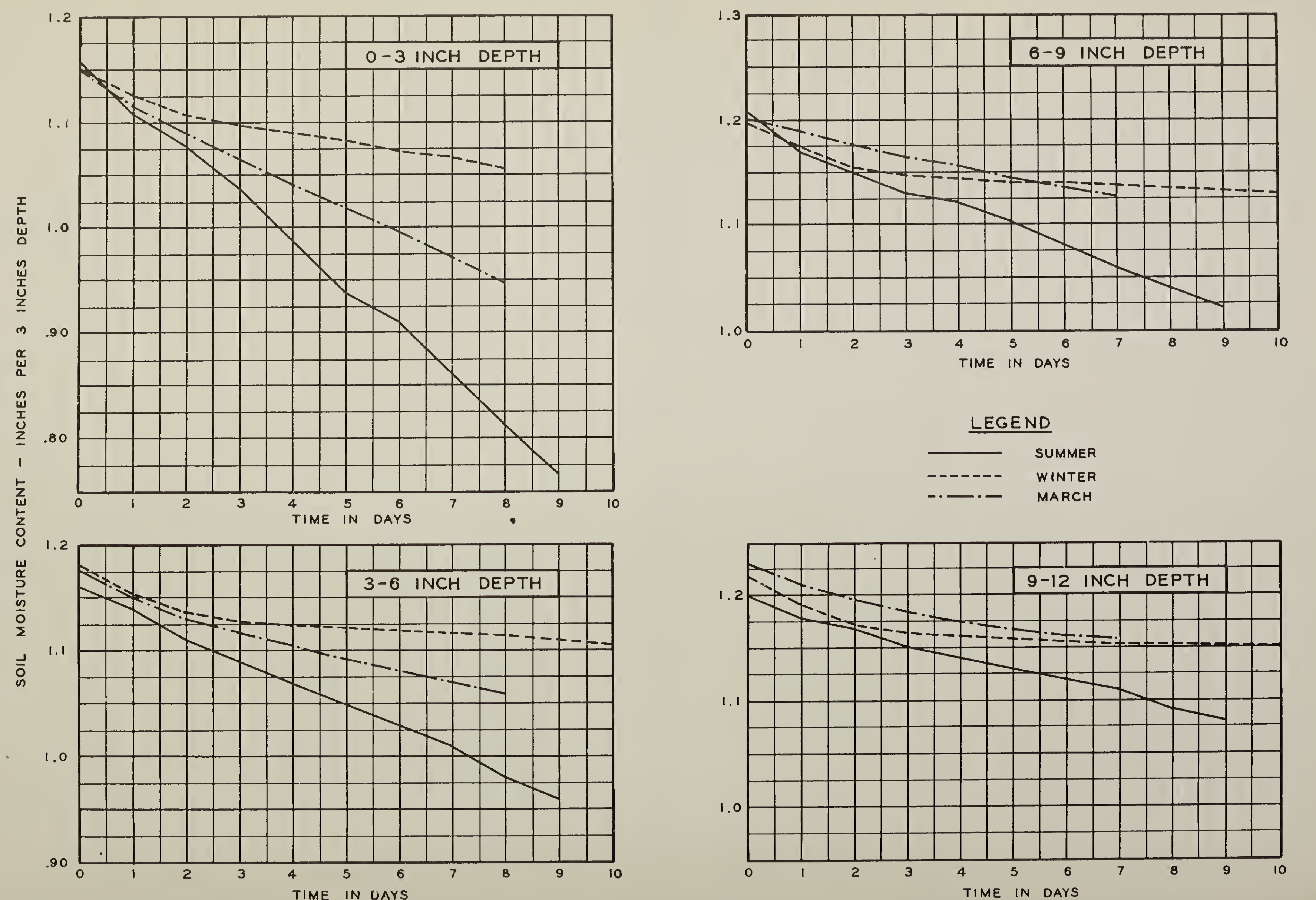

FIGURE 22. COMPARISON OF AVERAGE DEPLETION CURVES FOR SUMMER, WINTER AND MARCH

Location	Soil Depth, In.	Soil Water Loss, In. Summer	Winter
Mound	0-3	.041	.004
	3-6	.026	.001
	6-9	.026	.001
	9-12	.019	.001

In the comparison of winter and summer depletion for all sites, the period including the latter part of February and the month of March has to be considered separately. Figure 22 shows the average depletion curves for this period falling intermediately between the ones for winter and summer. This intermediate position is most apparent in the surface layers due to the gradual increase in transpiration associated with the regrowth of vegetative cover. Growth of the shallow-rooted annuals apparently is the determining factor.

Effect of Climate on Depletion

Differences in rates of winter, spring and summer depletion can be ascribed to seasonal differences in climate and vegetation. Among the climatic factors of importance are air temperature, humidity, and wind movement. In great part, the effect of these factors is integrated in evaporation measurements. Average monthly air temperature and evaporation from Weather Bureau Class A type pans at the Waterways Experiment Station (1939-1946)* are as follows:

* United States Department of Commerce, Weather Bureau, 1950, Mean Monthly and Annual Evaporation from Free Water Surface for the United States, Alaska, Hawaii and West Indies, Technical Paper 13.

Month	Average Temperature, F^{O}	Evaporation, In.
October	67.9	3.91
November	57.2	2.34
December	50.4	1.42
January	46.9	1.67
February	51.3	2.10
March	58.7	3.79

These values reflect the seasonal changes responsible for differences in the depletion curves: the comparatively high October temperature and evaporation, the similarities of these factors during the next four winter months, and the upward trends in March.

Still another climatic factor of importance was the frequent occurrence of rainfall keeping the soil wet and depletion periods short. For example, 46 rains occurred at Rifle; of these, 14 occurred with only one day between rains, and 42 occurred with seven days or less between rains.

While seasonal differences existed, no relationship was found between climatic factors and depletion rates within the 4-month winter season. For instance, the influence of climatic factors on the daily rate of soil moisture depletion was studied for the winter depletion periods in the 0-3-in. soil depth of Rifle and Mound sites. The factors studied included saturation deficit, minimum relative humidity, wind velocity at the 4-ft level, maximum air temperature, and soil temperature. Since the saturation deficit of the atmosphere usually correlates closely with evaporation rates, several expressions of saturation deficit were tried, namely the saturation deficit in terms of absolute humidity, and

in terms of vapor pressure, each the average of four measurements from 10 A. M. to 4 P. M.; and the vapor pressure deficit as the average of 12 values taken on alternate hours between the daily measurements of soil moisture. No relation was found between the daily rate of soil moisture loss and any of the factors. By plotting the daily loss of moisture against each of the factors, a scatter of points resulted with no apparent trend. Of interest is the similarity of moisture depletion between depletion periods as shown in Figure 18, regardless of the climatic variation within and between the drying periods.

Effect of Vegetation on Depletion

The effect of vegetation on depletion was most evident at the time of the first killing frost and after late February when spring growth started. The killing frost of November 3 marked the transition between summer and winter depletion rates. Thereafter, a succession of frosts kept the vegetation in a dormant state until late February when spring growth started.

The higher-than-normal temperatures during October followed by frosts in early November produced no clear-cut evidence of fall depletion curves. It is reasonable to assume that during years when temperature changes are not quite as abrupt, the gradual death of plant cover in the fall would produce depletion curves with an intermediate slope similar to that of early spring.

Within the winter period, no distinct influence of vegetation could be shown either between prediction sites or between tiers on one site. The low rates of depletion during this period, as compared with summer

rates, reflect the dormant state of the vegetation.

For the spring period, an attempt was made to relate vegetal growth to depletion by comparing the percentage of area occupied by live cover with daily rates of depletion. The comparison for the 0-3-in. soil depth at Park is as follows:

Depletion Period	Daily Soil Moisture Depletion (In.) Tier 2	Tier 1A	Tier 1C	Avg All Tiers	Average Per Cent Vegetation Density
2/5 - 2/11	.006	.019	.018	.010	72.
2/26 - 3/1	.000	.015	.032	.022	82
3/4 - 3/9	.010	.026	.040	.024	86
3/13 - 3/17	.010	.043	.045	.027	88
3/22 - 3/31	.004	.020	.038	.022	90

Some increase in rates as the season progressed is indicated. Similar trends and fluctuations were found in the Rifle and Mound records, but, as with Park, data were too few to be conclusive.

Effect of Water Table on Depletion

The wet conditions of the soil due to the frequent rainfalls generally masked the effect of change in ground-water levels on depletion rates. However, a 10-day record at Mound illustrates the effect of ground-water recession. Moisture contents and well depths during the period are given in Figure 23. Note that as the ground water dropped, depletion started at successive depths. After depletion started the rate of soil moisture loss was comparable to rates above field capacity shown in Figure 21. Under these conditions depletion was affected both by vapor losses and by downward movement of water.

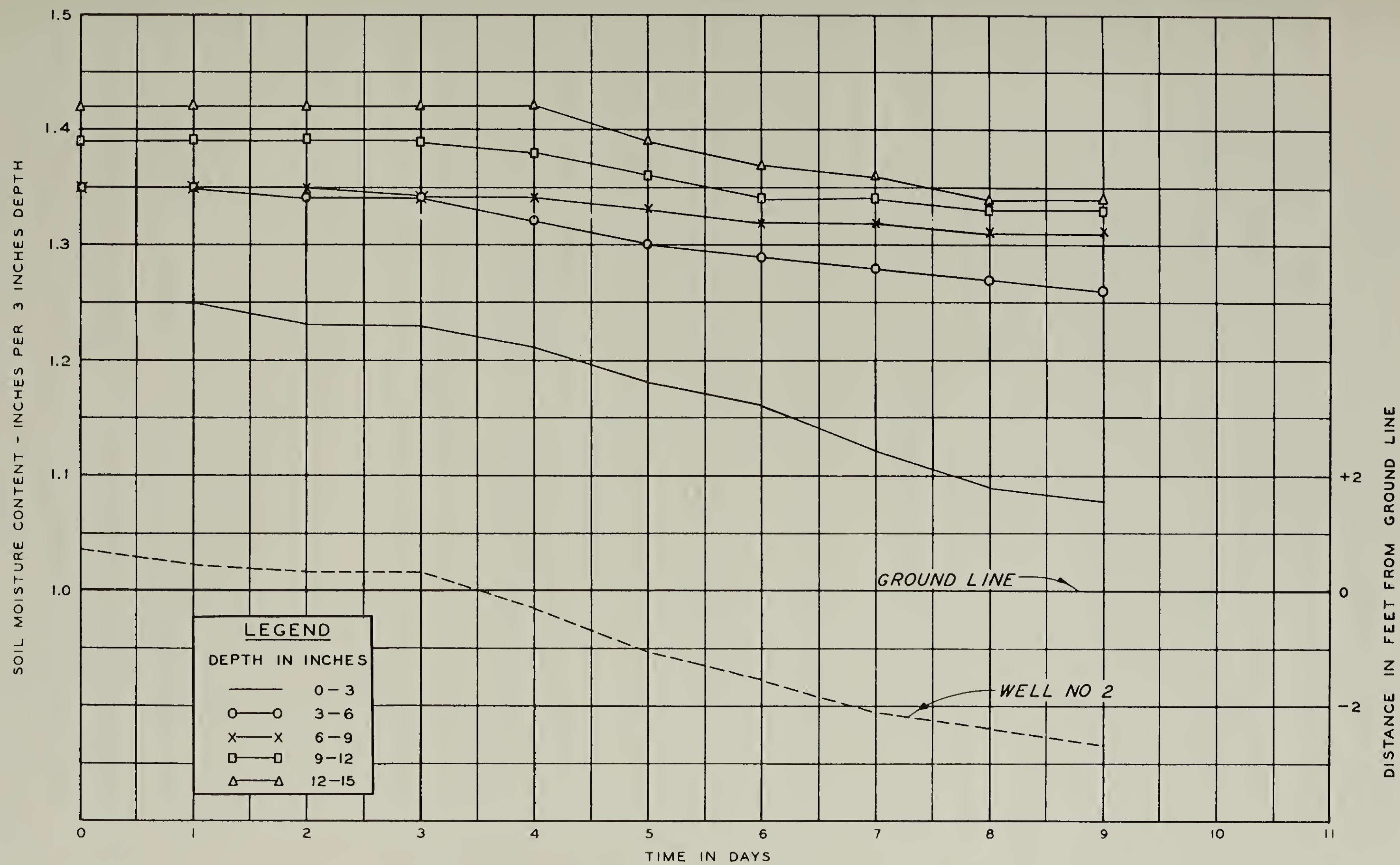

FIGURE 23. WATER TABLE EFFECT ON SOIL MOISTURE CONTENT AT MOUND SITE

LONG-TERM PREDICTION OF SOIL MOISTURE CONTENTS FOR THE WINTER SEASON

A ninety-day prediction was made for winter conditions from November 15, 1951 to February 16, 1952, for soil moisture content in the 6-9- and 9-12-in. depths at the Park, Rifle and Mound sites. Starting with known soil moisture contents of November 15, the prediction for the entire period was developed utilizing the rainfall records and the accretion and depletion prediction methods described in the present report.

The effect of storms on soil moisture content was evaluated by a system of routing the water into and out of the soil, deriving both soil moisture and available storage values. The available storage was determined by subtracting predicted moisture content from the maximum found during the winter season. The maximum values are listed in Table 20.

Table 20

MAXIMUM SOIL MOISTURE CONTENT IN INCHES PER 3 INCHES OF SOIL DEPTH

Site	Soil Depth, In.			
	0-3	3-6	6-9	9-12
Park	1.11	1.08	1.08	1.05
Rifle	1.15	1.14	1.22	1.29
Mound	1.27	1.37	1.40	1.40

Storms were classified on the basis of predicted available storage space in the 0-12-in. depth and the total rainfall. Depending on the storm class, the accretion and soil moisture content following the storm were predicted. Rainfall less than 0.25 in. was assumed to wet the 0-6-in. depth only. From the predicted soil moisture content following a storm,

subsequent daily soil moisture contents during a drying period were read directly from the depletion curve. This procedure was repeated for each storm and drying period.

Results for Park, Rifle and Mound are shown in Figure 24 through 26, respectively. The prediction method is given in detail for Rifle site from December 5 through 20, 1951. The 0-3-in. and 3-6-in. depths are combined into the 0-6-in. depth. The prediction is summarized in Table 21. Hereafter reference to the table will be made by date and column number. The maximum soil moisture contents are recorded at the head of columns 2 through 4.

On December 5 the moisture contents in the 0-6-in., 6-9-in , and 9-12-in. depths were 2.26, 1.19, and 1.26 in., respectively. No rain occurred between meter readings of December 5 and 6; consequently, the soil lost moisture and the average depletion curves, Figure 20, are entered to determine the amount. After a 24-hour period from the moisture content values given for December 5, the moisture contents in the 0-6-in. (combining 0-3-in. and 3-6-in.), in the 6-9-in. and in the 9-12-in. depths are 2.16 in., 1.14 in., and 1.21 in., respectively (columns 2 through 4 of Table 21) for December 6.

After the meter readings on December 6, 0.30 in. of rain occurred. In order to estimate accretion, the storm is first classified. The available storage is determined as the difference between the maximum moisture and the predicted moisture content of December 6, and is recorded in columns 5 through 7 of Table 21 for December 6. The available storage for the 0-12-in. depth, 0-29 in., is less than the rainfall; consequently, the storm falls in Class II (column 8). With a Class II storm the 0-6-in.

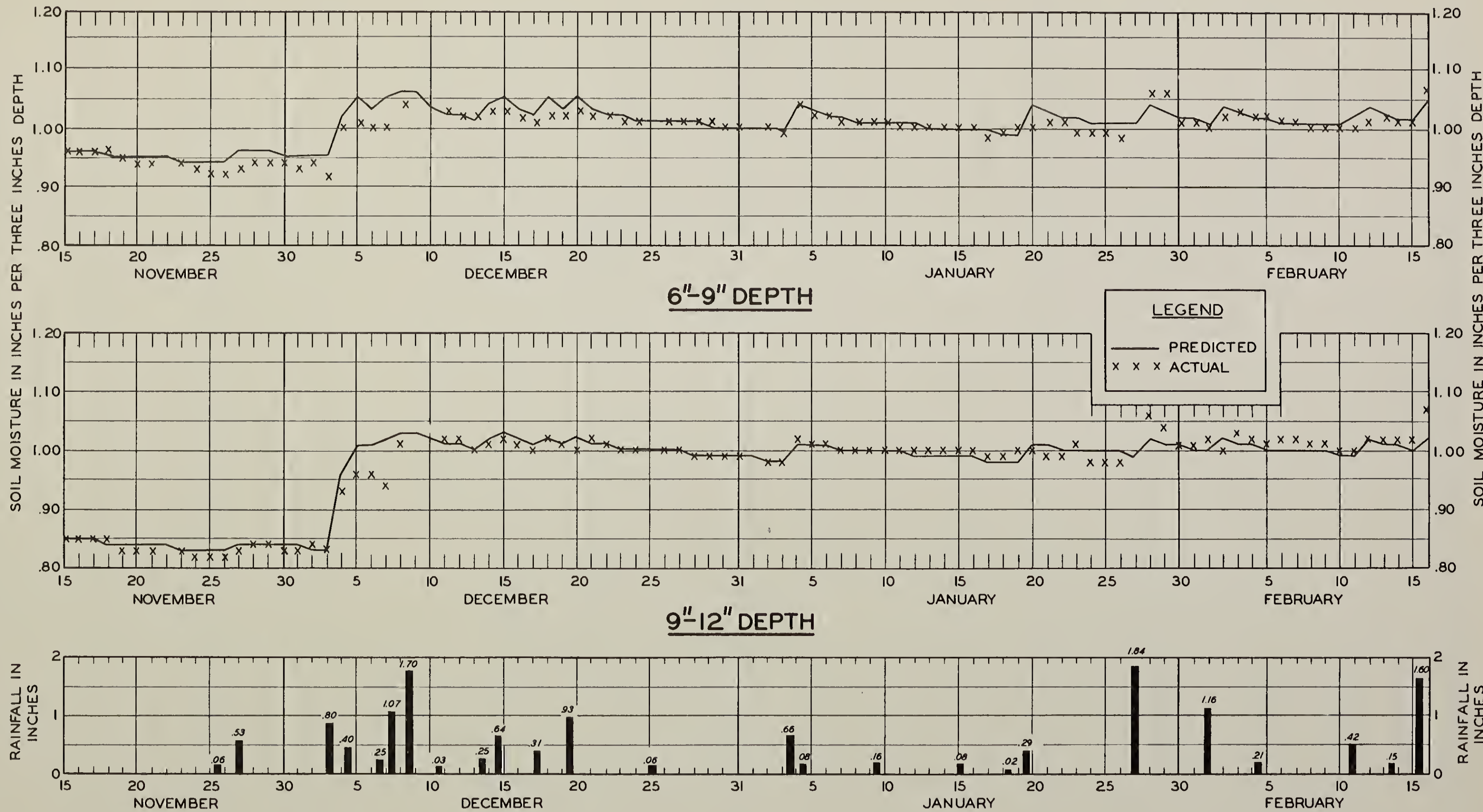

FIGURE 24. NINETY-DAY SOIL MOISTURE PREDICTION
PARK SITE - WINTER, 1951-1952

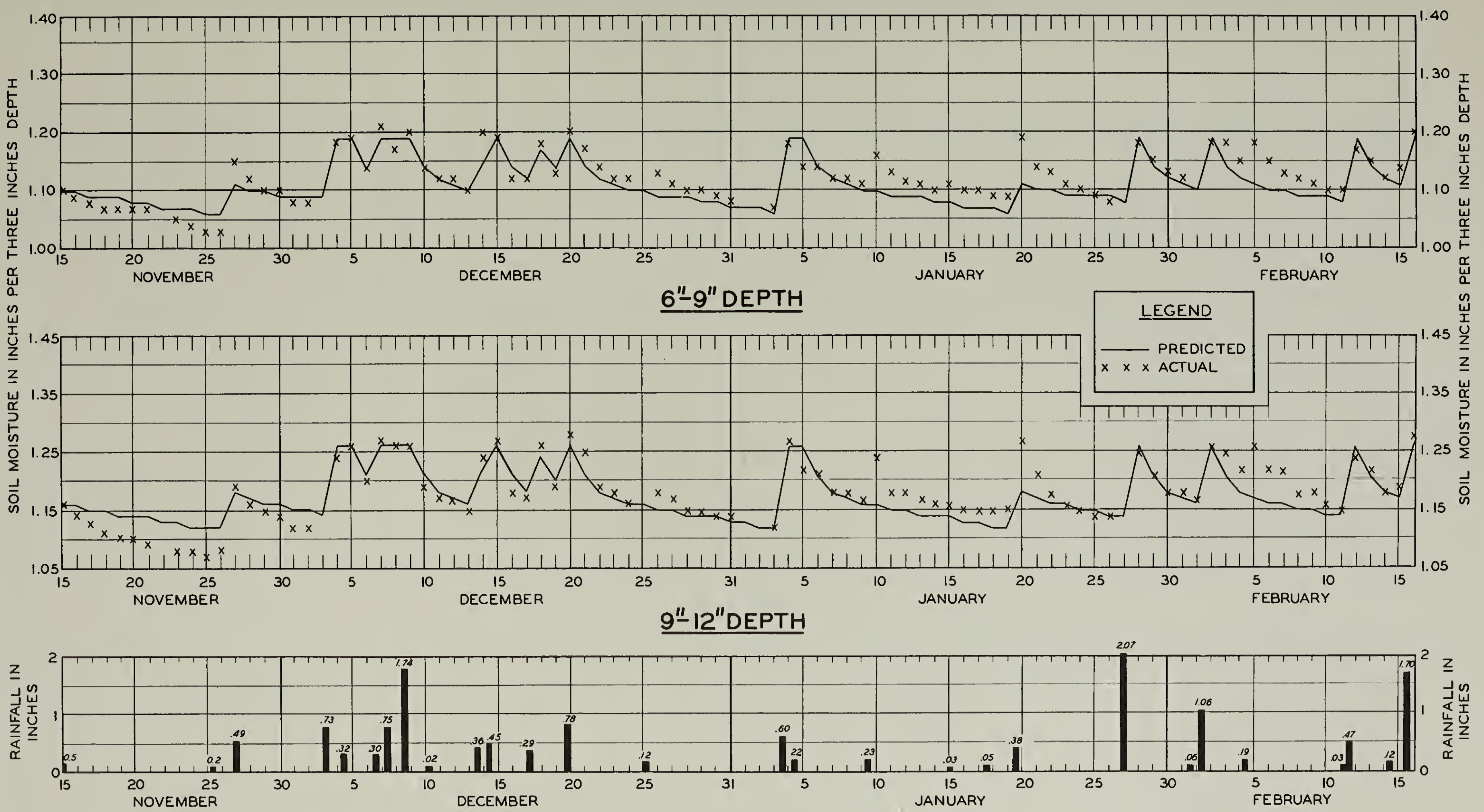

FIGURE 25. NINETY-DAY SOIL MOISTURE PREDICTION
RIFLE SITE - WINTER, 1951-1952

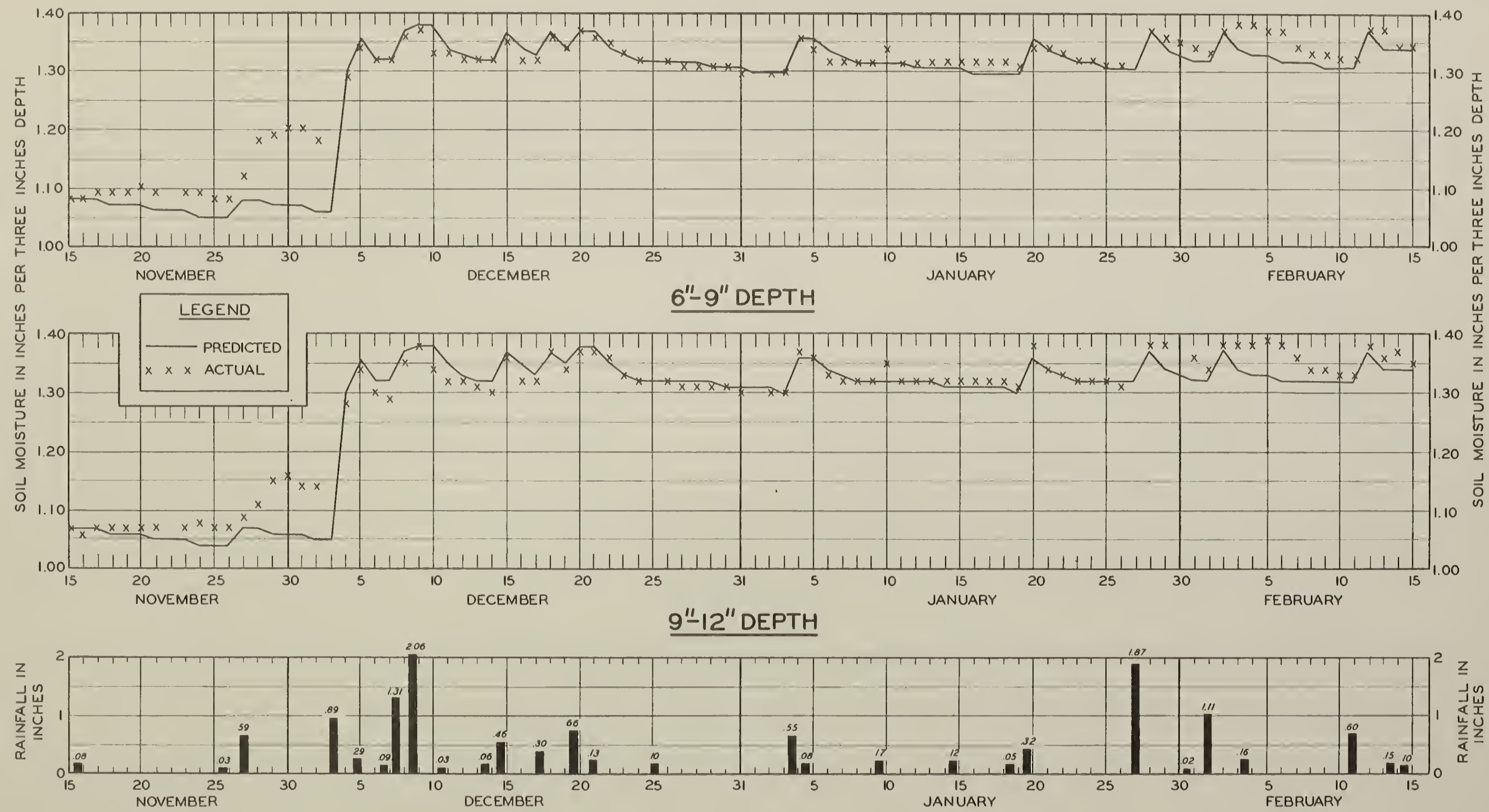

FIGURE 26. NINETY-DAY SOIL MOISTURE PREDICTION
MOUND SITE - WINTER, 1951-1952

Table 21

PREDICTION OF SOIL MOISTURE CONTENT AT RIFLE SITE
FROM DECEMBER 5 THROUGH 20, 1951

	Rain-fall in In.	Inches per 3 Inches of Soil Depth									
		Predicted Moisture Content			Predicted Available Storage			Storm	Accretion		
		0-6	6-9	9-12	0-6	6-9	9-12	Class	0-6	6-9	9-12
Date	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Max.		2.29	1.22	1.29							
Dec. 1951											
5		2.26	1.19	1.26							
6	0.30	2.16	1.14	1.21	0.13	0.08	0.08	II	0.13	0.05	0.05
7	0.75	2.29	1.19	1.26	0.00	0.03	0.03	II	0	0	0
8	1.74	2.29	1.19	1.26	0	0.03	0.03	II	0	0	0
9		2.29	1.19	1.26							
10	2	2.16	1.14	1.21							
11	0.02	2.12	1.12	1.18							
12		2.11	1.11	1.17							
13	0.36	2.10	1.10	1.16	0.19	0.12	0.13	I-W	0.19	0.05	0.06
14	0.45	2.29	1.15	1.22	0	0.07	0.07	II	0	0.04	0.04
15		2.29	1.19	1.26							
16		2.16	1.14	1.21							
17	0.29	2.12	1.12	1.18	0.17	0.10	0.11	I-W	0.17	0.05	0.06
18		2.29	1.17	1.24							
19	0.78	2.16	1.14	1.20	0.13	0.08	0.09	II	0.13	0.05	0.06
20		2.29	1.19	1.26							

depth is assumed to reach field saturation, consequently the accretion for this depth (column 9) will equal the available storage, (column 5) on December 6.

Accretion for the 6-9-in. and 9-12-in. depths is then estimated as follows: Entering Figure 12, for Class II storms, an available storage of 0.08 in. (columns 6 and 7) gives an accretion of 0.05 in. for each of these depths (columns 10 and 11). The predicted moistures and accretions of December 6 are added to give the predicted moisture contents for December 7 (columns 2 through 4).

On December 7, 0.75 in. of rain fell. With the soil nearly saturated, no accretion occurred even though the 6-12-in. depths had a slight amount of available storage (refer to Figure 12). A similar condition existed on December 8 when 1.74 in. of rain fell, and soil moisture was predicted to remain constant again. No rain fell between meter readings of December 9 to 11, and the daily moisture content was predicted from the depletion curves of Figure 20.

On December 11, 0.02 in. of rain fell which was added to the moisture content of 2.12 for the 0-6-in. depth. Entering the depletion curves at 2.14 in. moisture content for the combined depths of 0-3-in. and 3-6-in., the predicted value 24 hours later of 2.11 in. is found (column 2 of December 12). The predicted moisture at the other depths on December 11 and for all depths on December 12 follows the depletion curves in the usual manner.

On December 13, 0.36 in. of rain fell which is less than the available storage of 0.44 in. in the 0-~~6~~12-in. depth; therefore, this storm falls in Class I-W. The predicted values of 0.05 and 0.06 in. for the 6-9-in.

and 9-12-in. depths are given in Table 16. This amount, 0.11 in., deducted from the rainfall of 0.36 in. leaves sufficient water to satisfy available storage, 0-19 in., in the 0-6-in. depth.

The accretions are added to the moisture contents of December 13 to give the predicted moisture of December 14.

A Class II storm occurred on December 14 followed by two days of depletion, a Class I-W storm, one day of depletion and then a Class II storm. Accretion estimates for these storms were made in the manner described; the available storage was determined, the storm classified, and accretion determined from Table 16 and Figure 20. Between storms daily moisture contents were estimated using the depletion curves in Figure 12.

The 90-day predictions for the three sites were made in like manner using Table 15 and Figures 11 and 19 for Park, and Table 17 and Figures 13 and 21 for Mound.

The predicted values agree very well with the actual soil moisture contents. A summary of deviations between predicted and actual values is given in Table 22 for the 88 recorded days from November 15, 1951, to February 16, 1952 at Park, Rifle, and Mound sites. The percentage of deviation of 0.05 in. or less of soil moisture per 3 in. of soil depth in the 6-12-in. layer is 96.6 per cent. The average deviation is .02 in. and the predicted values of greatest deviation range from -0.13 to +0.08 in.

Table 22

DEVIATION OF PREDICTED FROM ACTUAL SOIL MOISTURE CONTENT IN THE 6-9- and 9-12-IN. SOIL DEPTHS, WINTER PERIOD

For 88 recorded days from November 15, 1951 to February 16, 1952

Site	Deviations 0.05 In. or Less: Number of Days, 6-9 In.	Number of Days, 9-12 In.	Per Cent of Total, 6-9 In.	Per Cent of Total, 9-12 In.
Park	88	87	100	99
Rifle	85	85	97	97
Mound	83	82	94	93
Total	510		96.6	

Site	Inches of Water: Deviation Range, 6-9 In. −	6-9 In. +	9-12 In. −	9-12 In. +	Average Deviation, 6-9 In.	Average Deviation, 9-12 In.
Park	.03	.05	.05	.08	.01	.01
Rifle	.08	.05	.09	.05	.02	.02
Mound	.13	.05	.10	.04	.02	.02
Total	-.13 to +.08				.02	

NOTE

The foregoing section completes the report on methods of predicting soil moisture content for the winter season.

The next two sections of this report deal with studies pertaining to other aspects of soil moisture prediction. The first is a continuation of the discussion of summer soil moisture depletion given in Progress Report I. The second section constitutes a review of the results from special studies which have been conducted during the past year.

The report is concluded with a brief presentation of future plans.

PREDICTION OF SOIL MOISTURE DURING SUMMER PERIODS OF SOIL MOISTURE DRYING

One of the objectives of the second six-month period of the pilot study was a re-evaluation of the summer soil moisture depletion in regard to (1) difference in depletion rates between prediction sites, (2) the relation of soil moisture tension to depletion, (3) theoretical concepts involved, and (4) a comparison of soil moisture depletion curves from other regions.

Differences in Depletion Rates Between Prediction Sites

Under summer conditions water is removed from the soil by: (1) its downward movement under the influence of gravity, (2) evaporation, and (3) transpiration. Each of these processes is limited by the forces which govern it. The downward movement of water is limited by the force exerted by gravity. Evaporation, with a much greater potential force than that of gravity, is limited to affecting relatively shallow soil depths through which the water vapor may effectively move out of the soil. Transpiration is limited to the depth of the root system and the tension of approximately 15 atmospheres which plants can exert on soil moisture.

Each of these forces affects the shape of the soil moisture depletion curves obtained at Park, Rifle, and Mound. Because these forces are universal, the shapes of these curves tend to be somewhat similar for all the sites. Although the shapes are similar, the curves do not coincide due to differences in physical characteristics of the soils, particularly their waterholding characteristics.

These differences are reflected in the graphical position of the soil moisture depletion curves. Curves for Mound, with moisture contents at field capacity and wilting point of 1.24 and 0.90 in. for the 0-3-in. depth (based on tension data), occupy a different position than those of Rifle; for instance, with comparable values of 1.12 and 0.31 in.

The similarity in shape of the curves was evident in the depletion curves shown in Progress Report I. As the wilting point was approached, curves for each site and depth showed a marked reduction in depletion rates. The maximum rate of depletion was at intermediate moisture contents. At high moisture contents, the rates were generally less than maximum values.

The rates are given in Table 23 for the three portions of the curves. The low rates of loss at low moisture contents for the four 3-in. increments between 0-12-in. are 0.008, 0.006, 0.007 in. per day for Park, Rifle and Mound, respectively. Differences, as may be expected, are not statistically significant either between sites or depths.

For the maximum rates of loss, differences in rates between depths are highly significant; between sites, nonsignificant. The least significant difference of 0.008 in. probably indicates no real difference between depletion rates of the lower three and signifies a real difference between these rates and those in the upper 6 in. of soil. This difference is probably due to the greater effect of evaporation in the upper layer.

Low rates of loss in the upper moisture range have been attributed, in Progress Report I, to the low transpiration rates in early spring. This explanation is not entirely correct, for in some curves these low

Table 23

AVERAGE DAILY RATES OF MOISTURE LOSS IN INCHES FOR SIMILAR DEPLETION PERIODS

Soil Depth, In.	Park Loss per Day, In.	Rifle Loss per Day, In.	Mound Loss per Day, In.	Mean for All Sites Loss per Day, In.
	Low Rates of Loss in Upper Moisture Range			
0-3	----	.028	----	
3-6	.020	.020	----	
6-9	.014	.022	----	
9-12	.008	.021	.010	
12-15	.009	.014	----	
	Low Rates of Loss in Lower Moisture Range			
0-3	.006	.008	.010	.008
3-6	.010	.006	.006	.007
6-9	.006	.006	.006	.006
9-12	.010	.004	.007	.007
12-15	----	----	.006	----
	Maximum Rates of Moisture Loss			
0-3	.043	.049	.042	.045
3-6	.038	.035	.026	.033
6-9	.024	.030	.027	.027
9-12	.020	.024	.019	.021
12-15	.017	.016	.025	.019

rates persist for summer periods, as for example in most of the curves shown in Figures 4 through 13 in Appendix L of Progress Report I for Park and Rifle. Nor does this explanation generally hold true for Mound.

A more acceptable explanation may be found in considering the effect of slow moisture drainage. Winter accretion data for all sites show some downward movement of water after the second and third days following rainfall. Because of relatively high evapo-transpiration losses during the summer, these movements were not as distinguishable in the summer soil

moisture record as in the winter record of relatively low rates. Slow drainage appears to be a characteristic of the loessial and alluvial soils of Park and Rifle. Russell (10), for instance, cites the work of several investigators which show that slow or delayed drainage in deep loessial and alluvial soils may continue for many months. If this occurs at the prediction sites, it may explain the lower rates of depletion at high moisture contents, the accretion from slow drainage serving to dampen the effect of evapo-transpiration. Note in Table 23 that this dampening does not occur at the 0-3-in. depth at Park and is progressively more pronounced at greater depths, a condition supporting the possibility of slow drainage. Rifle data indicate this to a lesser degree.

The similarity of depletion rates was brought out in replotting of soil moisture depletion curves. In Figure 27 depletion curves for five depths at Park have been plotted to bring the wilting points together, and thus allow a comparison of rates from this point. In essence, this graphically portrays the data of Table 23, the similarity in rates at low moisture content, the differential at high moisture contents, and the tendency to have similar rates within 0-6 in. and 6-15 in. for intermediate moisture contents. Figure 28 is a similar graph of the Rifle curves again illustrating differences in the data in Table 23 with the depths between 0 and 12 in. tending to have similar maximum and minimum rates. Figure 29, for Mound, shows a striking similarity of the depletion curves for all but the 0-3-in. depth. The similarities of these curves at high moisture content, in contrast to those of Park and Rifle, may be due to the fact that the types of drainage affecting the Park and Rifle curves do not occur in the impervious clay at Mound.

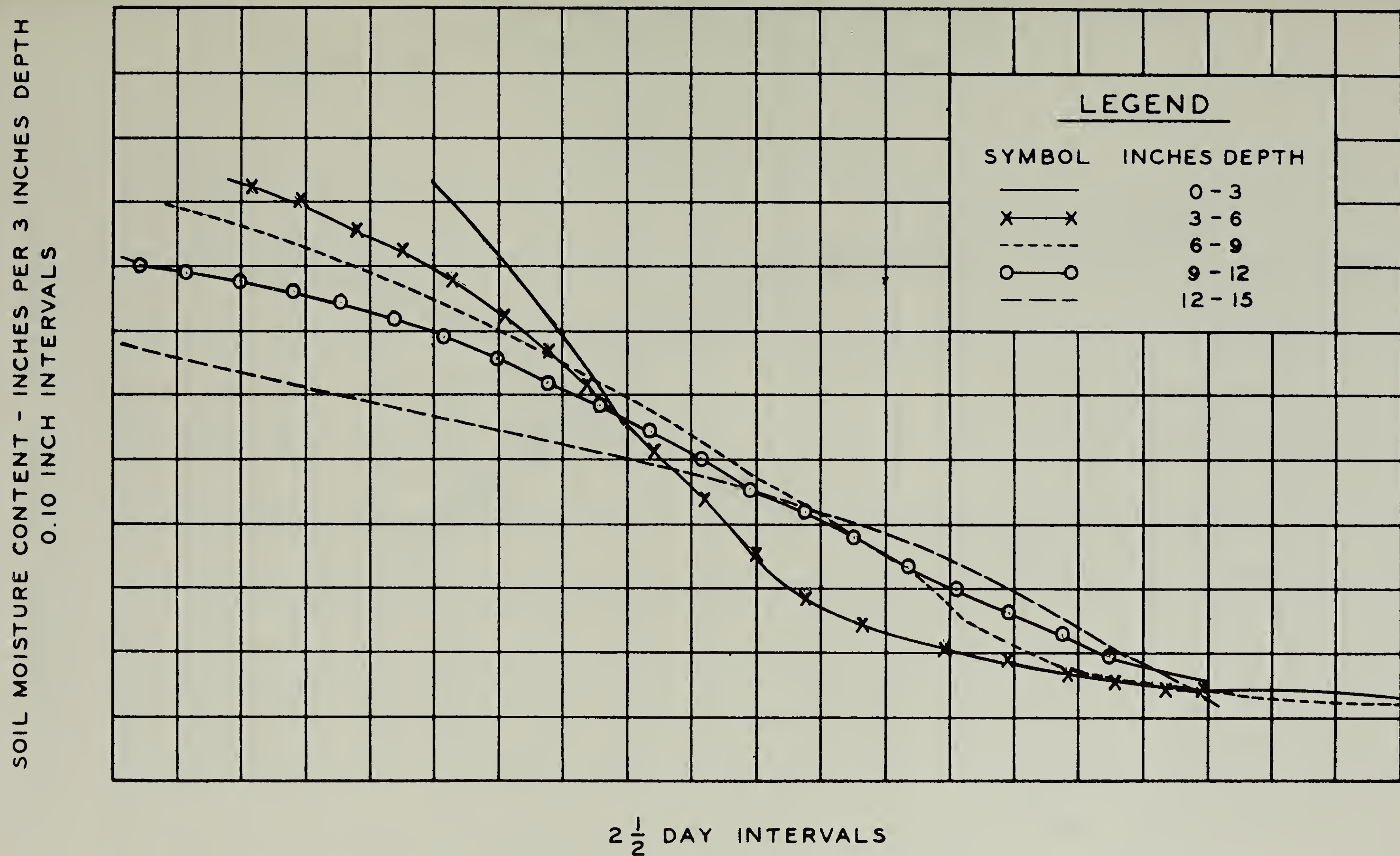

FIGURE 27. SOIL MOISTURE DEPLETION CURVES AT PARK PLOTTED FROM A COMMON WILTING POINT

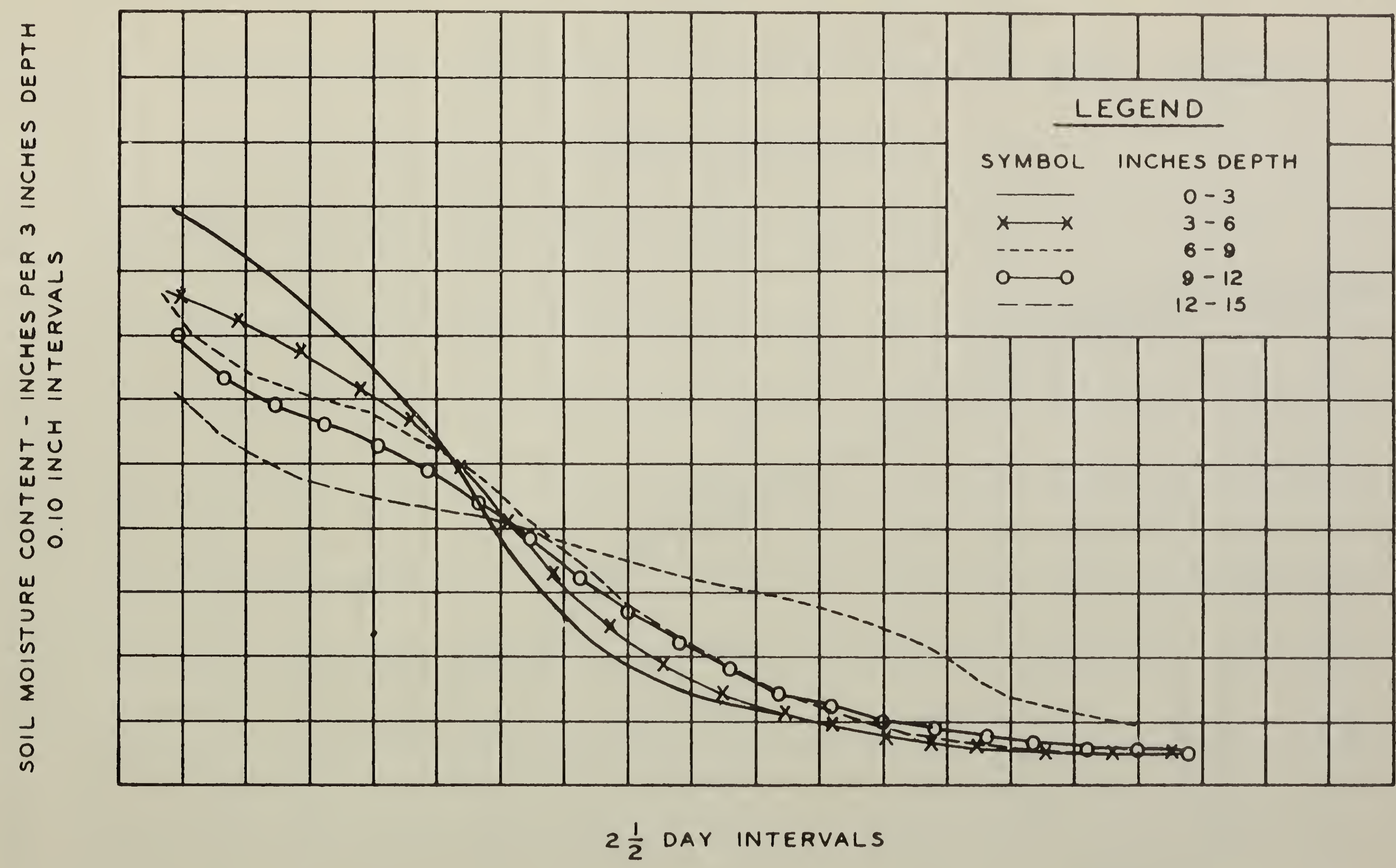

FIGURE 28. SOIL MOISTURE DEPLETION CURVES AT RIFLE PLOTTED FROM A COMMON WILTING POINT

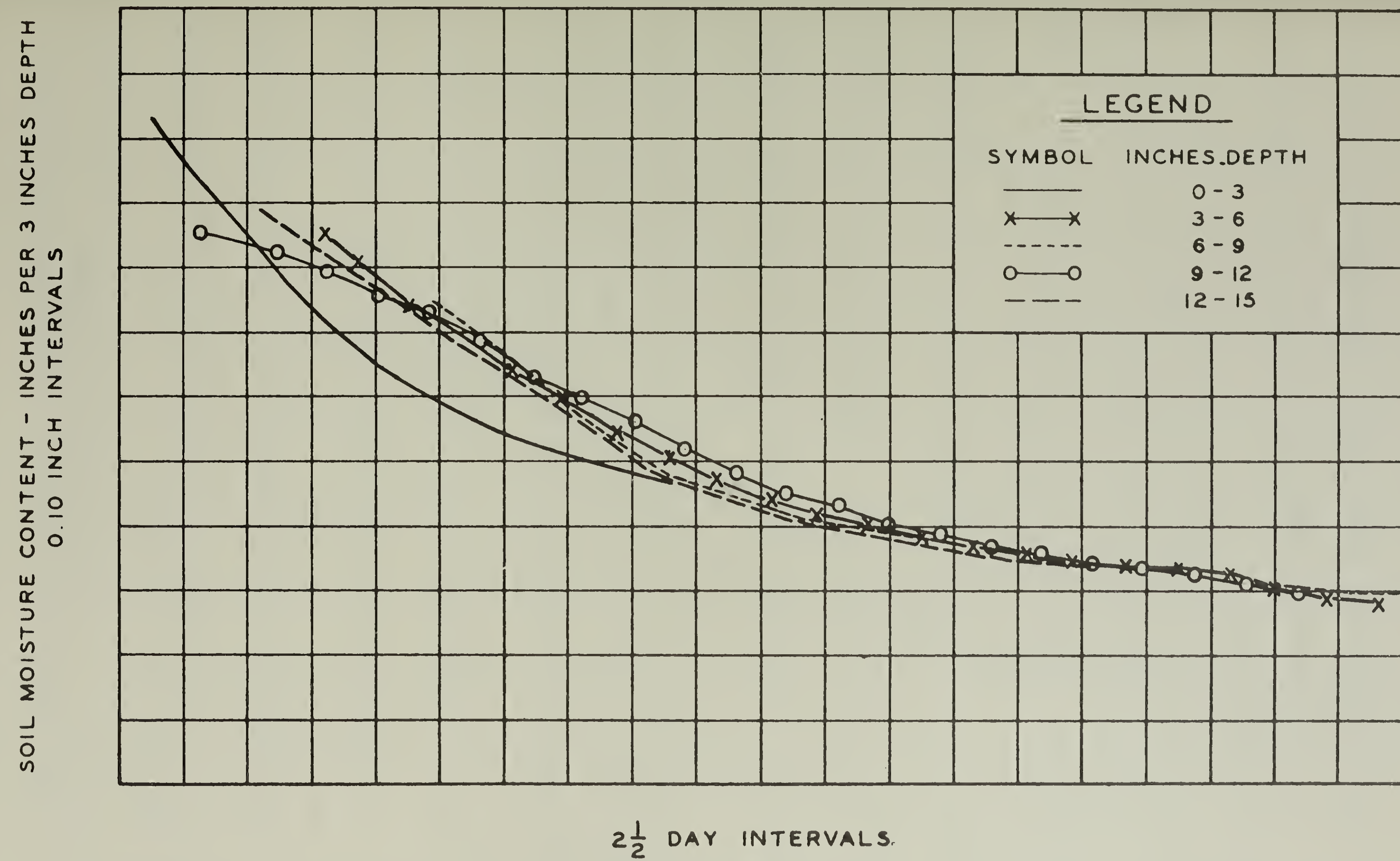

FIGURE 29. SOIL MOISTURE DEPLETION CURVES AT MOUND PLOTTED FROM A COMMON WILTING POINT

Further evidence that the depletion curves at each site are quite similar, is given in Figure 30 which depicts the depletion curves composited from the five depths at each site, these curves being derived from Figures 27, 28, and 29.

When depletion curves are plotted with a common wilting point, as was done in Figures 27, 28, and 29, they begin at an equivalent tension. This again raises the interesting question whether equivalence in tension would be continued throughout the depletion curve. An attempt was made to compare depletion tensions in Progress Report I. This comparison, however, showing little similarity between the sites, was not entirely valid since it was based on comparing the entire range of tension from 0 to 15 atmospheres. Depletion data less than 0.3 atmospheres should not have been included, for within this range depletion is due to gravitational force in addition to evapo-transpiration, and depletion rates due to gravity flow would vary considerably between the different soils. Replotting the depletion curves in terms of tension from 0.3 to 15 atmospheres for the 0-3- and 9-12-in. depths gives the relation shown in Figures 31 and 32. Immediately evident is the similarity of these curves contrasted to the differences in position of the depletion curves, on a moisture content basis, shown at the bottom of the figure. In the tension curves, the depletion rate for Mound 0-3-in. depth is much steeper than Park or Rifle rates. Again, this may be due to conditions at Mound which favor high rates of evaporation.

This re-evaluation of summer soil moisture depletion data leads to the following conclusions:

a. At low moisture contents the rates were similar with no

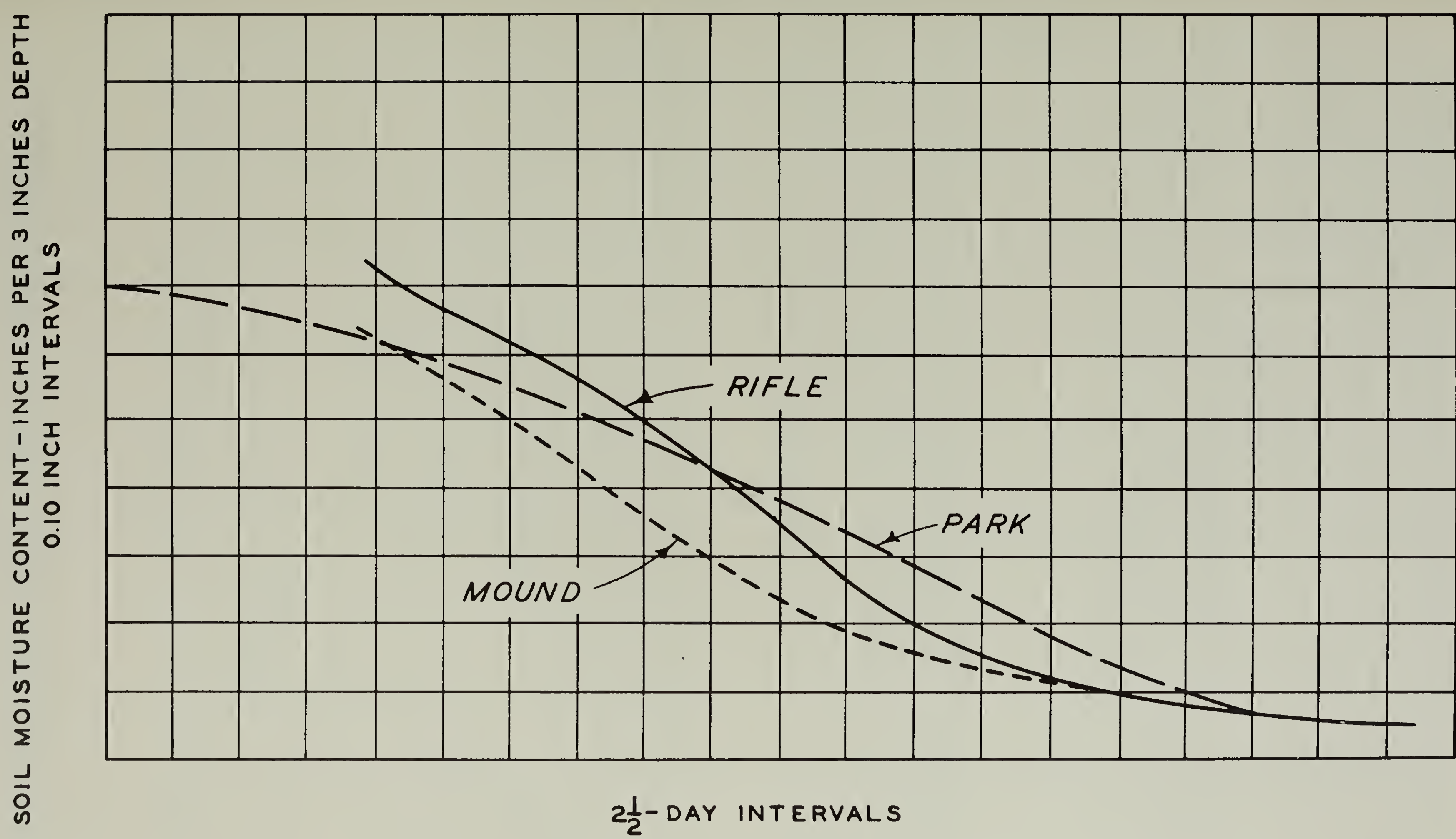

FIGURE 30. COMPOSITE DEPLETION CURVES FOR 0-15 INCH DEPTH FOR EACH SITE

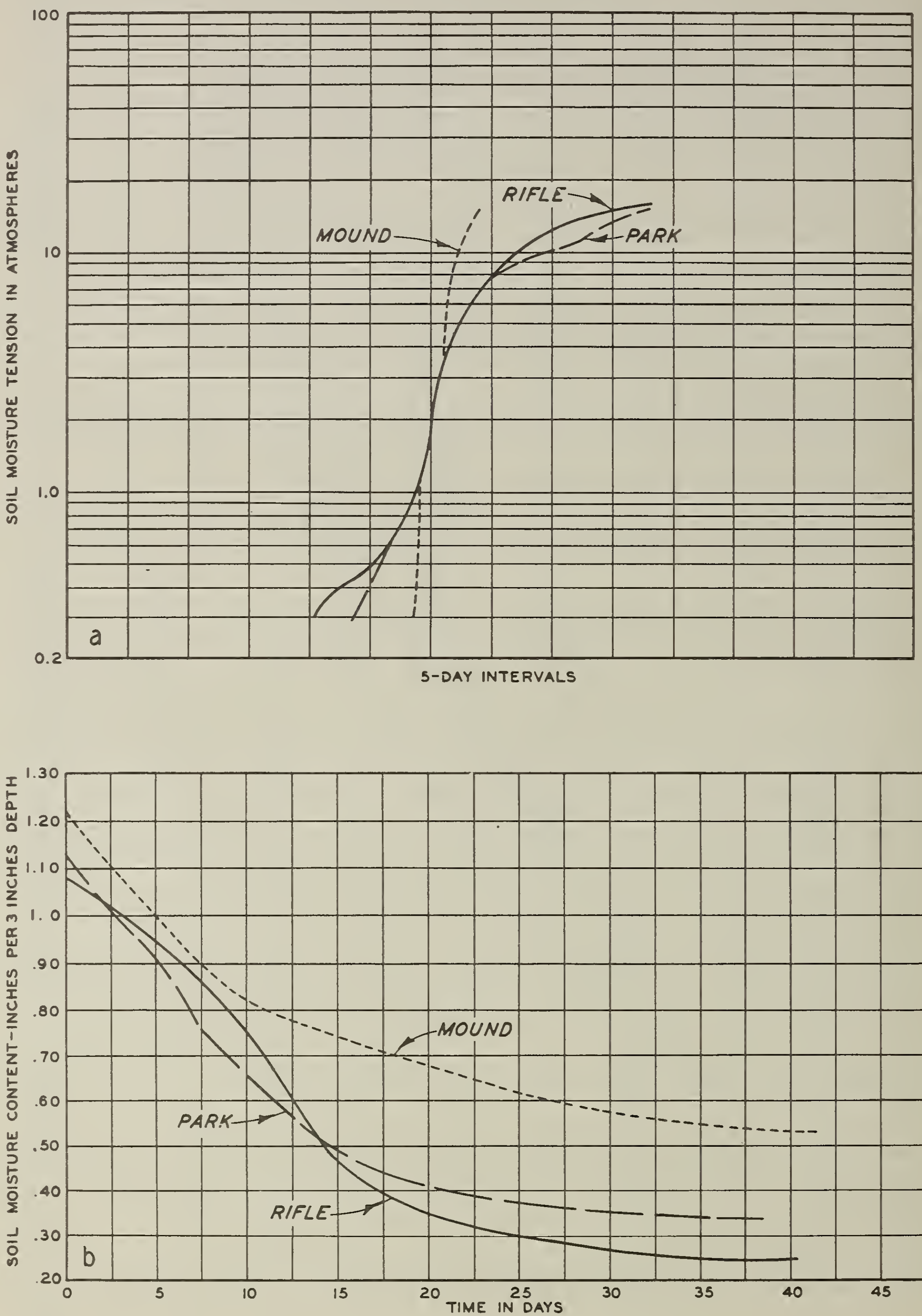

FIGURE 31. DEPLETION CURVES FOR 0-3 INCH DEPTH IN TERMS OF (a) ATMOSPHERES TENSION AND (b) MOISTURE CONTENT.

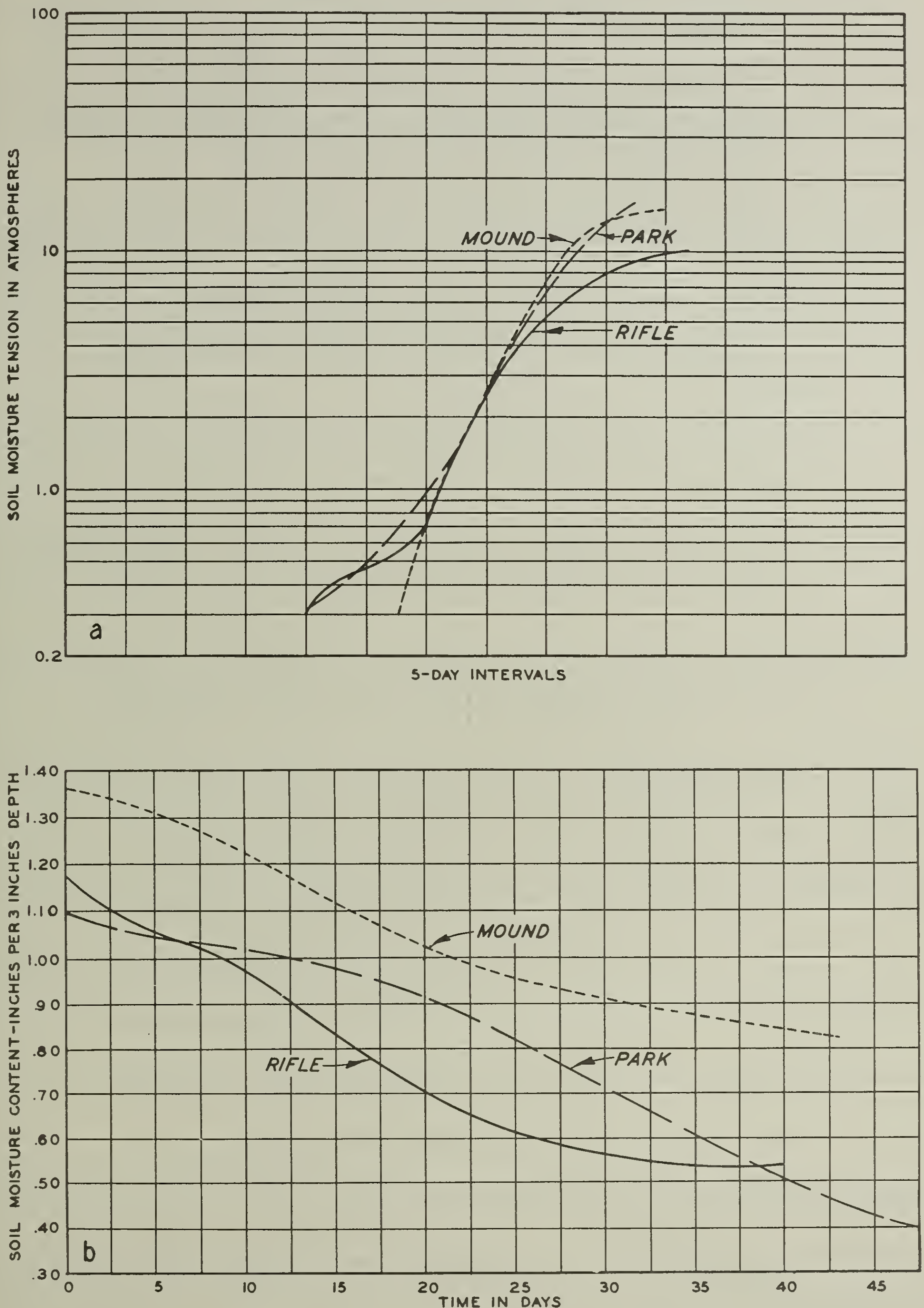

FIGURE 32. DEPLETION CURVES FOR 9-12 INCH DEPTH IN TERMS OF (a) ATMOSPHERES TENSION AND (b) MOISTURE CONTENT.

statistically significant difference between sites or depths.

b. Differences between maximum depletion rates were not statistically significant between sites. Between depths, differences were highly significant.

c. In a graphical comparison of rates, depletion curves for Park very nearly coincide for the 0-6- and 6-15-in. depths at intermediate moisture contents. Rifle curves for the 0-12-in. depth were very similar throughout the same range. The four curves for Mound between 3 and 15 in. agreed closely throughout their entire range.

d. Composite depletion curves for the 0-15-in. depth, expressed in inches of water per 3 inches of soil depth, were very similar in shape at each site.

e. Plotting depletion in terms of tension for values greater than 0.3 atmospheres showed a close agreement between the 9-12-in. depth curve for all sites.

Theoretical Concepts of Soil Moisture Depletion

In reviewing concepts of soil moisture depletion, a distinction was made between material describing conditions under which there were unlimited supplies of water from high water tables, and conditions where water tables were not a source of supply. In the latter, the moisture available to the plant, within the soil mass occupied by the roots, was limited except when replenished by rainfall. This case applies to the summer conditions on the Vicksburg prediction sites.

While the condition of unlimited supplies will not be discussed in this section to any extent, it is interesting to note that for prediction purposes each of the two conditions requires consideration of different site factors. This is brought out in Thornthwaite's statement (13):

> "When there is no deficiency of moisture in the soil and the roots are able to absorb the moisture freely, the rate and amount of transpiration are governed by atmospheric factors alone... If on

> the other hand, soil moisture is deficient, the importance of the condition of the atmosphere diminishes and that of soil moisture supply increases."

In other words for prediction of soil moisture depletion for upland conditions, the soil moisture supply, not atmospheric factors, is the most important factor. H. L. Penman (7) has noted the same thing:

> "The calculation of soil moisture deficit from weather data is only valid when there is adequate water available to meet the potential demand..."

It is also interesting to note that predictions of soil moisture depletion for both conditions have been based on energy relations. Under conditions of unlimited moisture supply, for instance, Penman (7) has calculated energy balances from which he estimated soil moisture deficit. His energy balance for May to September 1949 showing the percentage distribution of incoming radiant energy was as follows:

Energy Sink	Per Cent
Plant growth	1
Heating soil	2
Heating air	4
Reflection	20
Back radiation	34
Transpiration	39

Note the small amount of energy used for plant growth compared to that used for transpiration. From data of this kind Penman calculated potential evapo-transpiration for vegetal areas with an adequate water supply. In essence, Thornthwaite's method of estimation of potential evapo-transpiration (12) is based also on an analysis of radiant energy; in his study, day-length and temperature were the factors used for

predicting potential evapo-transpiration.

Where moisture supplies are limiting, the rates of soil moisture depletion have been described as a function of the energy relation developed between plant roots and moisture in the surrounding soil.

Kramer (5) discussing the availability of soil moisture to plants states:

> "From the standpoint of energy involved in movement of water from soil to plant, there can be little doubt that soil moisture becomes less and less readily available as the moisture content decreases from field capacity to the permanent wilting percentage. As the moisture content of the soil decreases, there is inevitably an increase in the amount of energy required to move a unit mass of water a unit distance."

He also points out that the availability will vary according to the texture of the soil:

> "For practical purposes, however, in many sandy soils water may be regarded as being equally available over most of the range from field capacity to permanent wilting... Most of the readily available water is removed from light soil before the tension on the remainder exceeds 1 atmosphere, and only a small fraction is held with sufficient force to hinder absorption. This is not true, however, in heavy clay, when 50 per cent or more of the available water sometimes is held with tensions in excess of 1 atmosphere. In such soils water actually does become limiting to growth before the moisture content is reduced to the permanent wilting percentages."

If moisture becomes less and less readily available as moisture content decreases, there then should be some agreement between soil moisture depletion curves for various soils when plotted in terms of tension. This is illustrated with the fairly close agreement obtained in plotting the tension-depletion curves for the 9-12-in. depth at each site (Figure 32).

Also, according to this concept, soil moisture depletion curves, plotted arithmetically should approximate hyperbola. The fact that the

depletion curves at Park and Rifle do not, may be due, as explained previously, to slow internal drainage which dampens depletion rates at high moisture content. There may be, however, a possibility that the moisture depletion rates for these sites are hyperbolic, the difference between the actual soil moisture depletion and the hyperbola representing the amount of accretion in the various depths.

Some evidence supports the view that rates of depletion vary with moisture content. Work and Lewis (17), for instance, found that rates of soil moisture loss under pear trees declined progressively, beginning before the average soil moisture content had approached permanent wilting percentage. Figure 33 gives their soil moisture record by one-foot depths. The hyperbolic nature of the curve for the 0-1- and 1-2-ft depths is quite evident, less so for the 2-3-ft depth and absent for the 3-4-ft depth. The authors also refer in this paper to unpublished work of the senior author in which he found that soil moisture is lost at a decreasing rate beginning when 50 to 60 per cent of the available soil moisture is still present.

Henrici (4), studying transpiration of herbaceous and forest vegetation has also reported that transpiration rates depend largely on the amount of soil moisture.

Schneider and Childers (11) in a study of transpiration of apple leaves found a 65 per cent reduction in transpiration rates before wilting was evident. In their study, they used an insulated chamber with controlled light, temperature and humidity, brought the soil to field capacity and measured transpiration. Of some interest is their observation that when water was applied after the trees were wilted, leaves

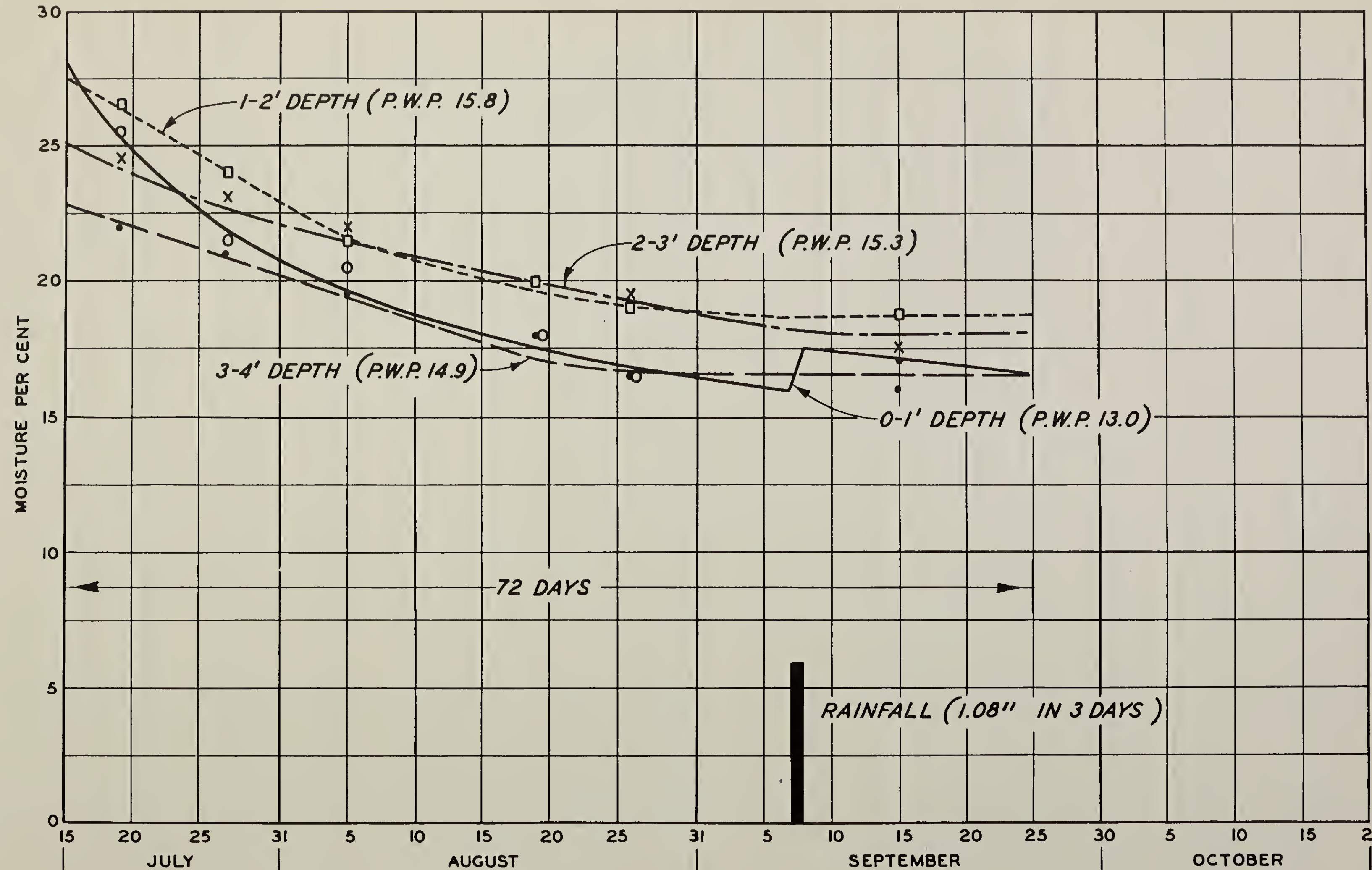

FIGURE 33. SOIL MOISTURE CONTENT UNDER A PEAR TREE, MEYER CLAY ADOBE (17).

regained turgidity in 3-5 hours but it took 2-7 days before transpiration rates returned to normal.

In regard to soil depth, the concept of decreasing rate of depletion with decreasing moisture content would apply throughout the depth of the soil occupied by plant roots. Throughout depths of root occupancy soil moisture would be removed at rates depending on the variation of soil moisture content and tension with depth. In a recent Forest Service Publication (6) this has been expressed as follows:

> "...the rate at which roots extract moisture decreases as soil moisture content is decreased, or, in relation to energy, when increased force is required to overcome the attraction of moisture to the soil particle. When moisture becomes available at a certain depth, the rate of extraction at this depth will be increased. During this time interval moisture extraction will continue at other depths, but at comparatively higher tension and lower rates. This indicates the operation of a governing relationship which tends to reduce the difference between the magnitudes of the forces involved in the extraction of moisture at the various depths. Thus at high moisture contents, soil moisture will be reduced more rapidly than at lower moisture contents, tending to bring the energy levels -- and the moisture contents -- together. Simply expressed: the higher the moisture content the faster the loss."

It should be noted here that similar soil moisture depletion rates at various depths in the root zone could not be expected unless the tension-soil moisture relationships at the various depths are also similar. Similarity in depletion rates would thus tend to indicate a rather uniform texture and structure throughout the profile.

Wadleigh (15) used the term "total stress" to signify the summation of moisture tension and osmotic pressure which governs the availability of soil moisture. In developing a mathematical method for evaluating variation in tension of soil moisture over a range of salt contents he assumed that:

"...soil moisture stress over the various portions of the absorbing surface of the root system tends to approach uniformity. This assumption is fully in accordance with the second law of thermodynamics, in that it is assumed that the plant will not absorb water at a higher energy level if water is available at a lower energy level when the system is at equilibrium."

There is no universal agreement that rates of soil moisture depletion decrease with reduction of soil moisture content. Veihmeyer and Hendrickson (14) state that soil moisture depletion, at least below the surface foot, slopes downward approximately uniformly until slightly above the wilting percentage, at which point there is a marked reduction in the rate of extraction: their soil moisture records for 0-1- and 1-2-ft depths for a variety of soils and vegetation appear in Figures 34 and 35. Similarities in depletion rates for these various conditions are evident. The 1-2-ft curves, and those for greater depths presented by the author, generally bear out their contention of a uniform rate of moisture loss until the permanent wilting percentage is approached. According to Esselen (1), soil moisture is equally available to citrus trees through the whole range from field capacity to just above wilting point.

In summary, the determination of whether soil moisture depletion rates are constant until a point close to wilting, or whether the rates gradually decrease, will depend to a great degree on the depth of soil being considered. In the upper soil layers where evaporation is active, the effect of evapo-transpiration would tend to give a hyperbolic curve since evaporation would be most effective at the higher moisture contents. Once the soil surface dries, evaporation is considerably reduced. At lower depths, where evaporation is not an important factor, the effect of soil water accretion from overlying layers may tend to reduce depletion

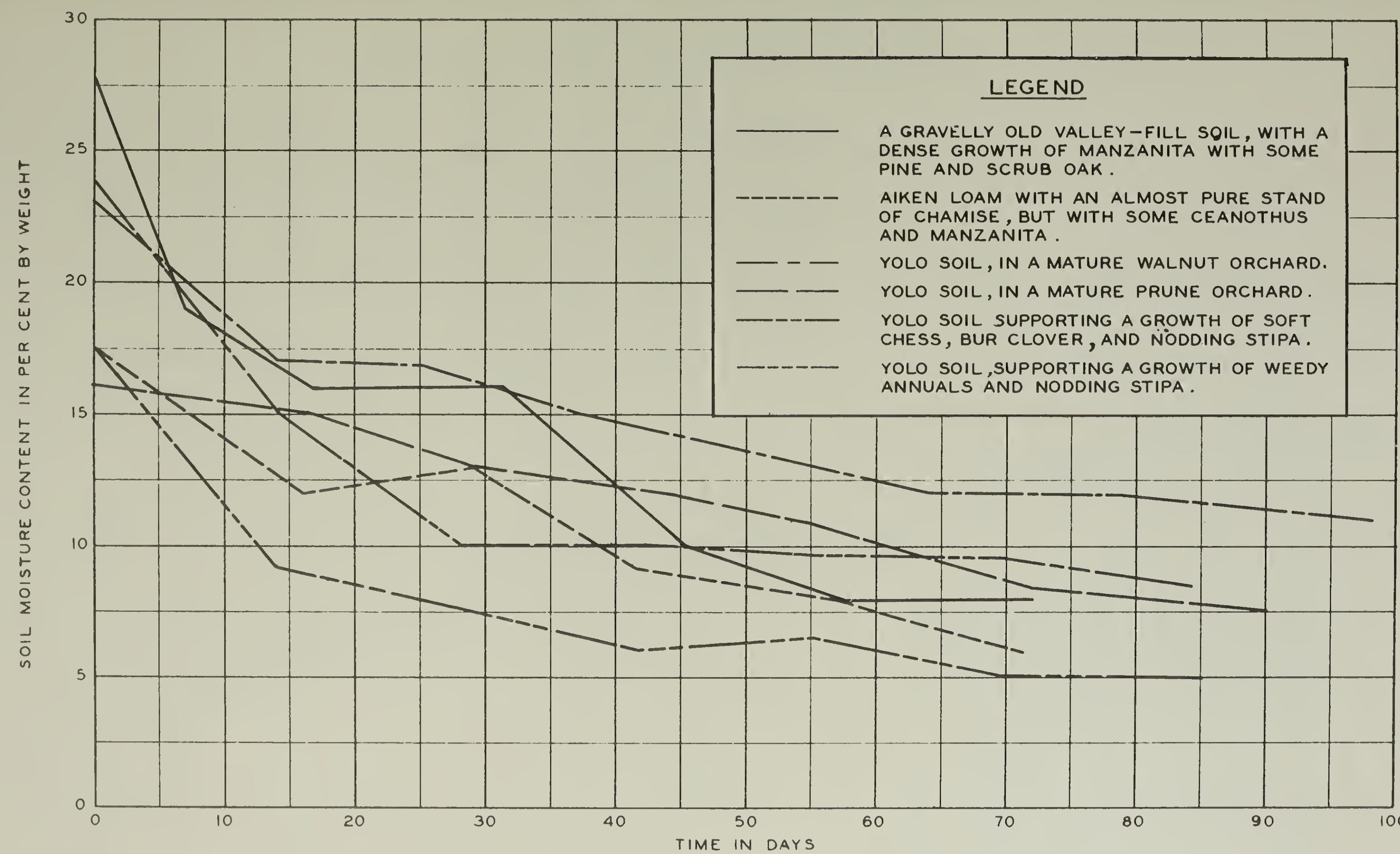

FIGURE 34. SOIL MOISTURE DEPLETION CURVES FOR 0–1 FOOT DEPTH

[FROM VEIHMEYER AND HENDRICKSON (14)]

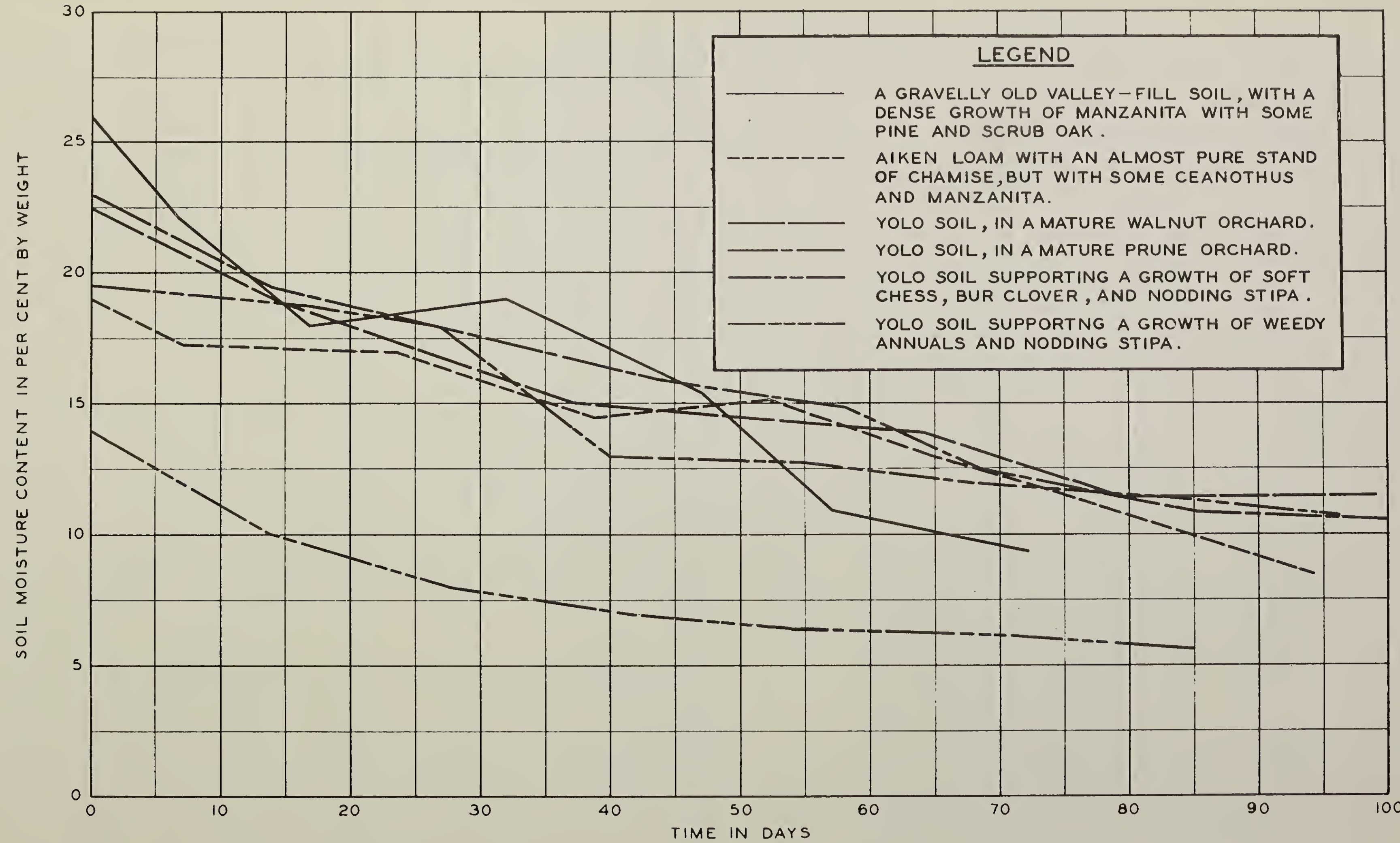

FIGURE 35. SOIL MOISTURE DEPLETION CURVES FOR 1–2 FEET DEPTH

[FROM VEIHMEYER AND HENDRICKSON (14)]

rates, giving either linear depletion curves in high moisture content ranges or even the flattened curves found at Park and Rifle sites.

Thus, at high moisture contents evaporation would steepen the depletion curve for the upper layers while for lower depths accretion from above would tend to flatten the depletion curves. In addition to these factors, the salinity of the soil solution would also affect the shape of the depletion curve. This is illustrated in Figure 36 from Wadleigh and Gauch (15). For the Vicksburg data this is not an important factor. As noted by Kramer (5), texture may also govern the shape of the depletion curve.

Soil Moisture Depletion Curves From Other Regions

A search of the literature for soil moisture depletion records from other localities revealed few to compare with those obtained at Vicksburg. In this literature, the moisture contents were taken mostly either weekly or biweekly which is too long an interval, particularly for humid regions, to give usable soil moisture depletion curves. Also, as would be expected, there were differences in the way soil moisture was expressed, both as to terms and soil depths, making comparison of records difficult. The few usable records located, showing depletion for 6 different areas, are given in Figures 33 through 35 and 37 through 44.

Figure 33, the soil moisture record under a pear tree (17), previously referred to, also shows a similarity in rates at different depths.

Figures 34 and 35, also from Veihmeyer and Hendrickson (14), give depletion curves for several sites differing in soils and vegetal cover. Both sets of curves, while apparently interrupted occasionally by rainfall,

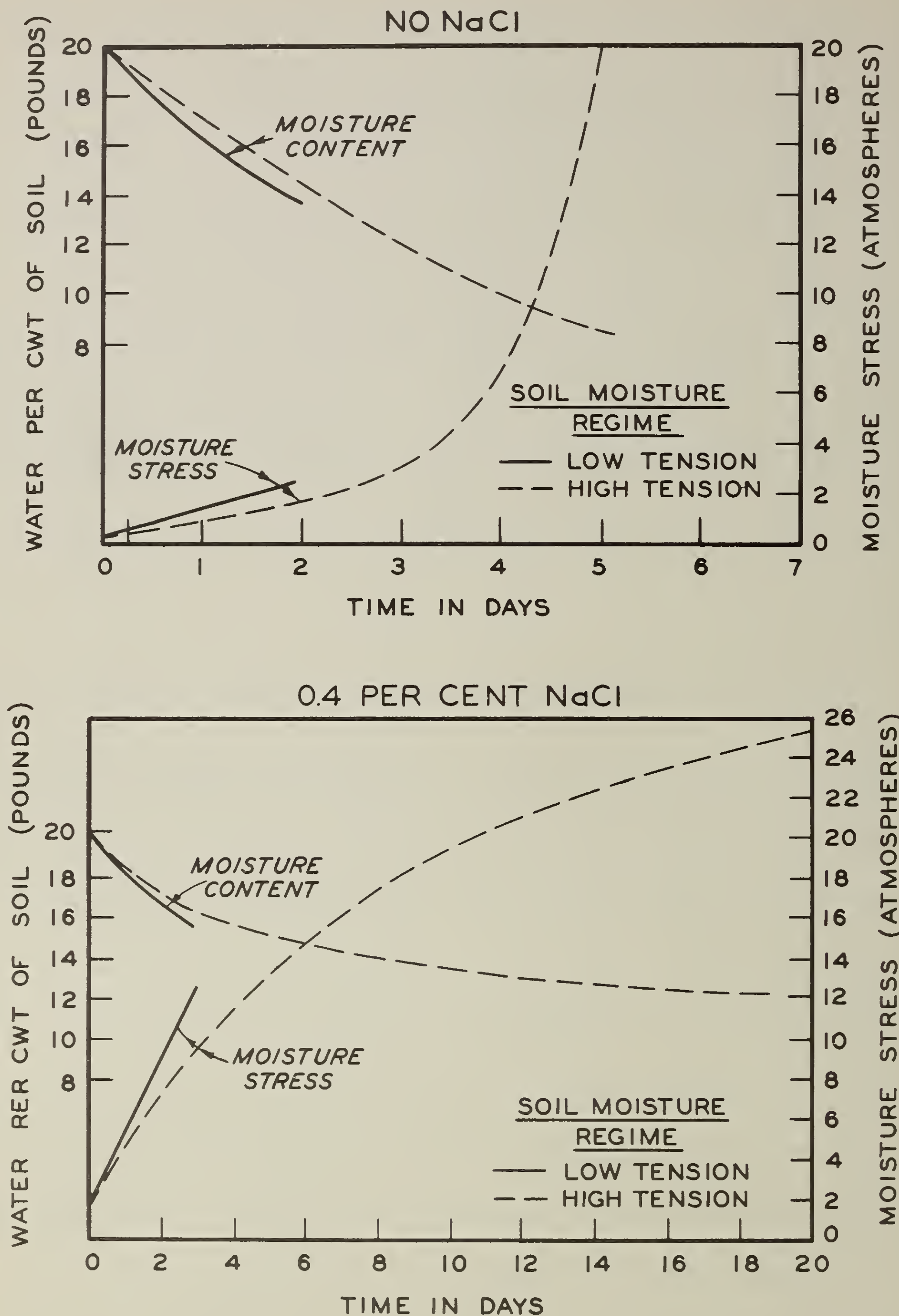

FIGURE 36. RATE OF CHANGE IN MOISTURE CONTENT AND MOISTURE STRESS WITH NO NdCl AND 0.4 PER CENT NdCl (FROM WADLEIGH AND GAUCH)

again show some similarity in rates. In the original paper the curves in this figure were plotted separately and were over-plotted here to allow comparison of rates.

Figure 37 gives soil moisture depletion curves from Hendrickson and Veihmeyer (3), that were used in the previously noted Forest Service Publication (6) to illustrate similarity in soil moisture depletion rates at various soil depths.

Figures 38, 39, and 40 illustrate the same tendencies for different vegetal cover and soils in California (9). These curves were offset in the original figure and were replotted over each other to show similarity in rates. Figure 41 is of particular interest as it illustrates the similarity in rates of depletion for four consecutive years.

Note that so far the above examples are for West Coast areas where dry seasons produce long and relatively unbroken periods of depletion.

Figures 42 and 43, for two localities in the east, reflect frequent rainfalls. Figure 42, a soil moisture record from Coshocton, Ohio, (2) again shows similarities in depletion rates between different soils and different years. In the original figure the ordinates were for moisture content for 0-40-in. depth and the curves were plotted by date. Replotting on the basis of moisture content per foot of soil and over-plotting the curves permit comparison of rates and amounts with other figures. Figure 43, from an Illinois study (8), shows a similarity in depletion rates for four different depths. These curves were originally plotted to give total moisture content at each depth.

Figure 44 illustrates several depletion curves from an irrigated orange orchard in South Africa (1). Considerable similarity is evident

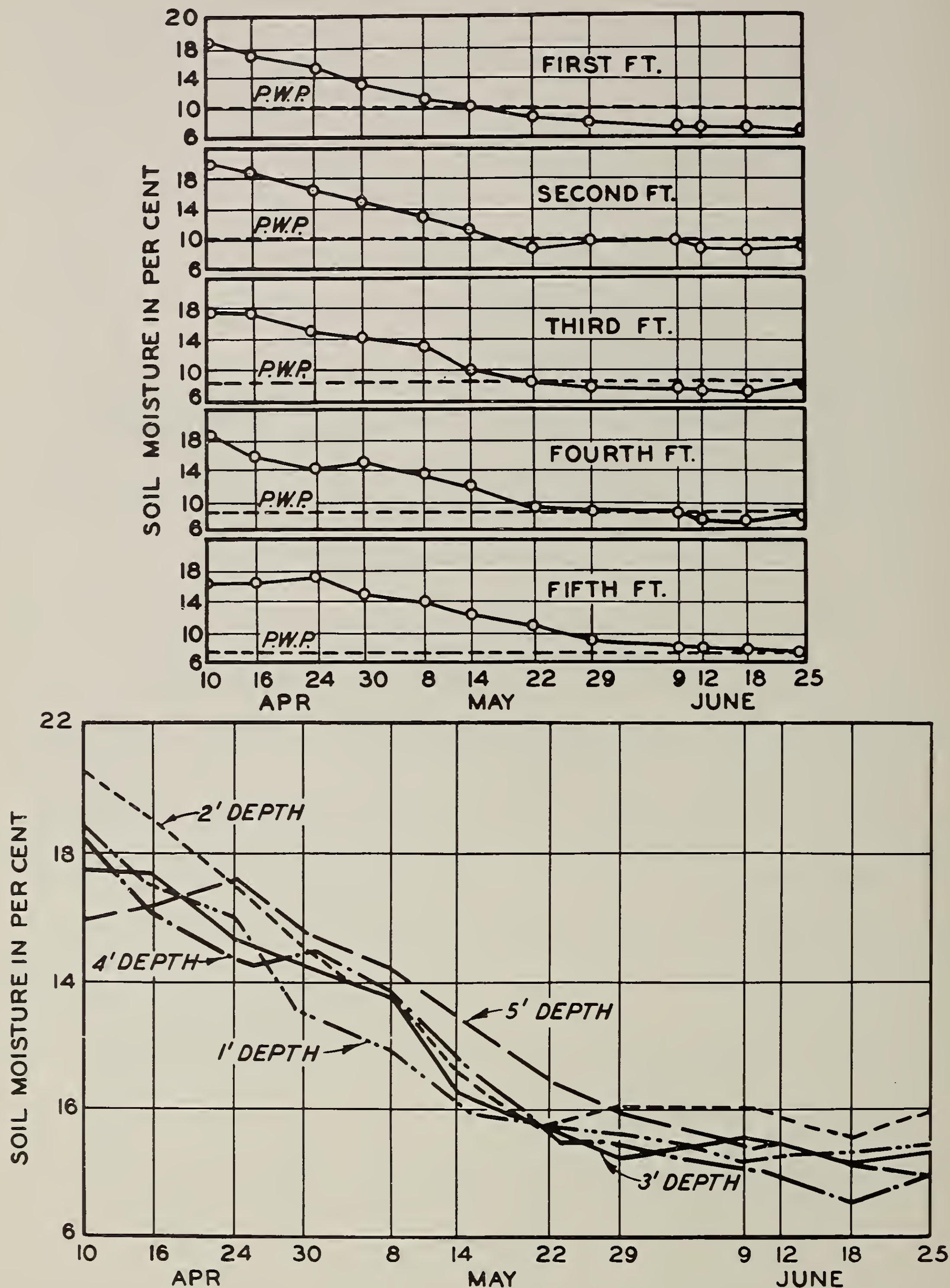

FIGURE 37. TOP-SOIL MOISTURE EXTRACTION CURVES OBTAINED WITH SUGAR BEETS ON YOLO LOAM. PERMANENT WILTING PERCENTAGES ARE INDICATED BY THE BROKEN LINES. BOTTOM-SUPERIMPOSURE OF THE ABOVE CURVES.

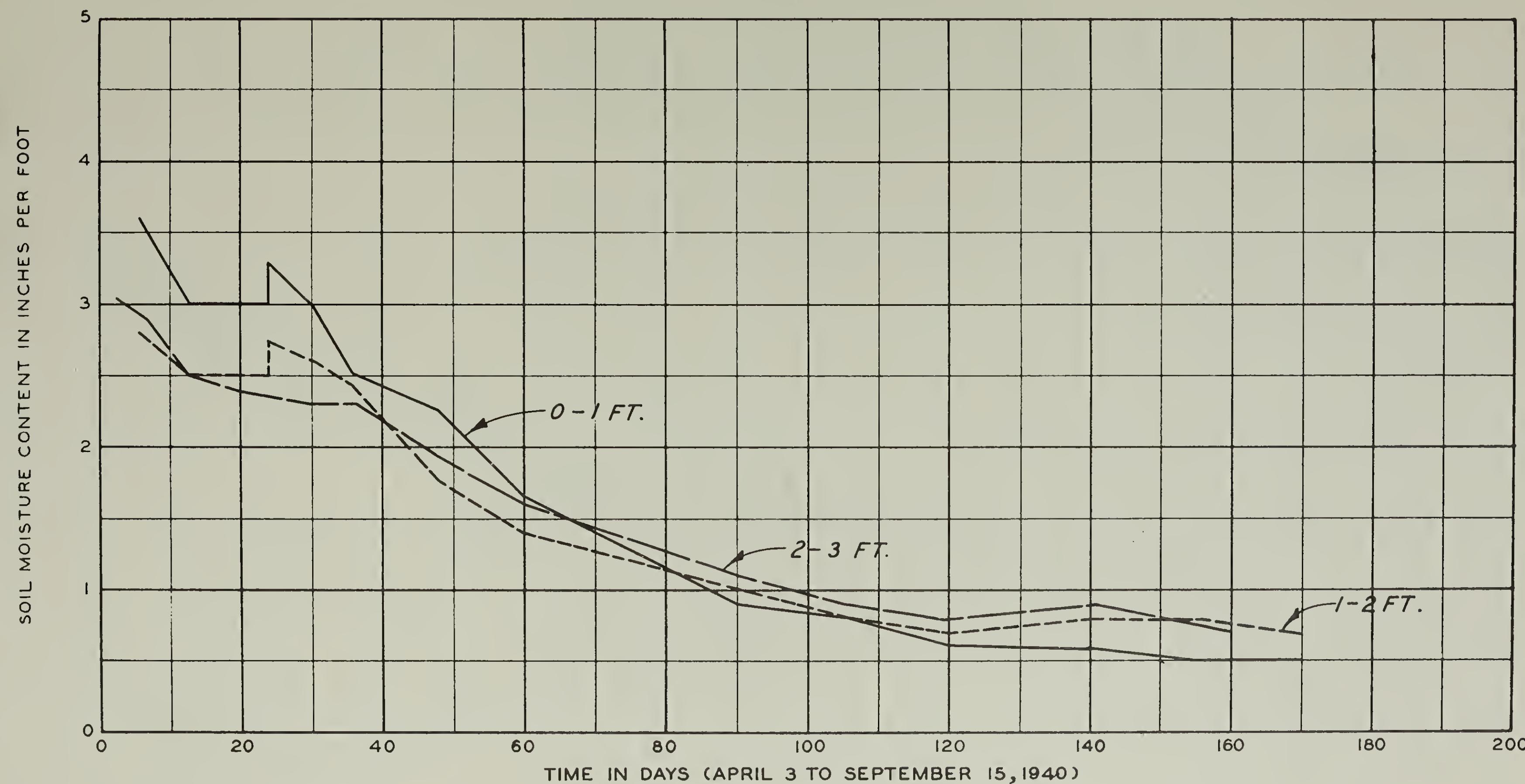

FIGURE 38. SOIL MOISTURE DEPLETION CURVES FOR SANDY CLAY LOAM WITH WOODLAND CHAPARRAL COVER
[FROM ROWE AND COLMAN (9)]

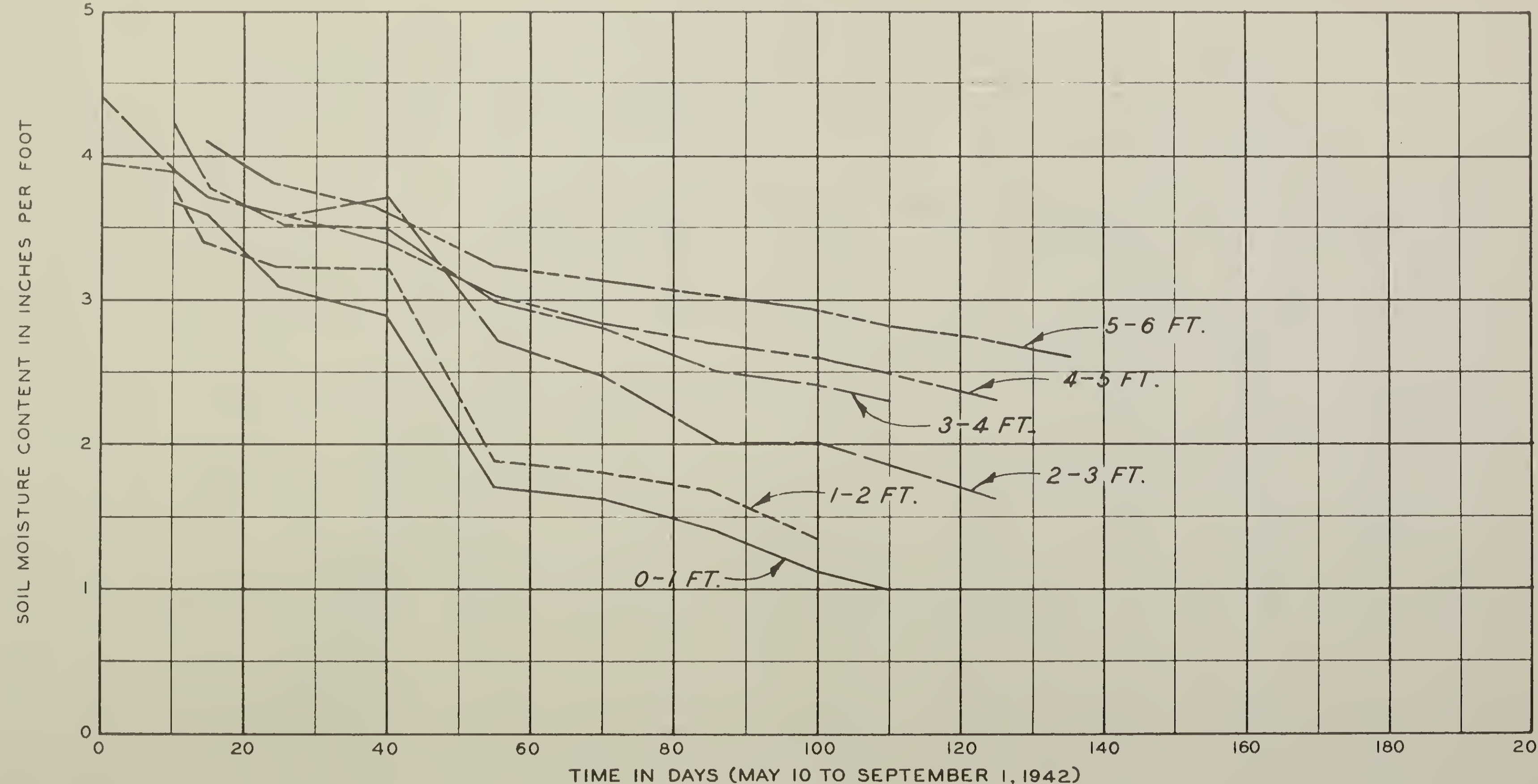

FIGURE 39. SOIL MOISTURE DEPLETION CURVES FOR SOIL WITH SURFACE FOOT OF FINE SANDY LOAM OVER CLAY LOAM, UNDER PONDEROSA PINES

[FROM ROWE AND COLMAN (9)]

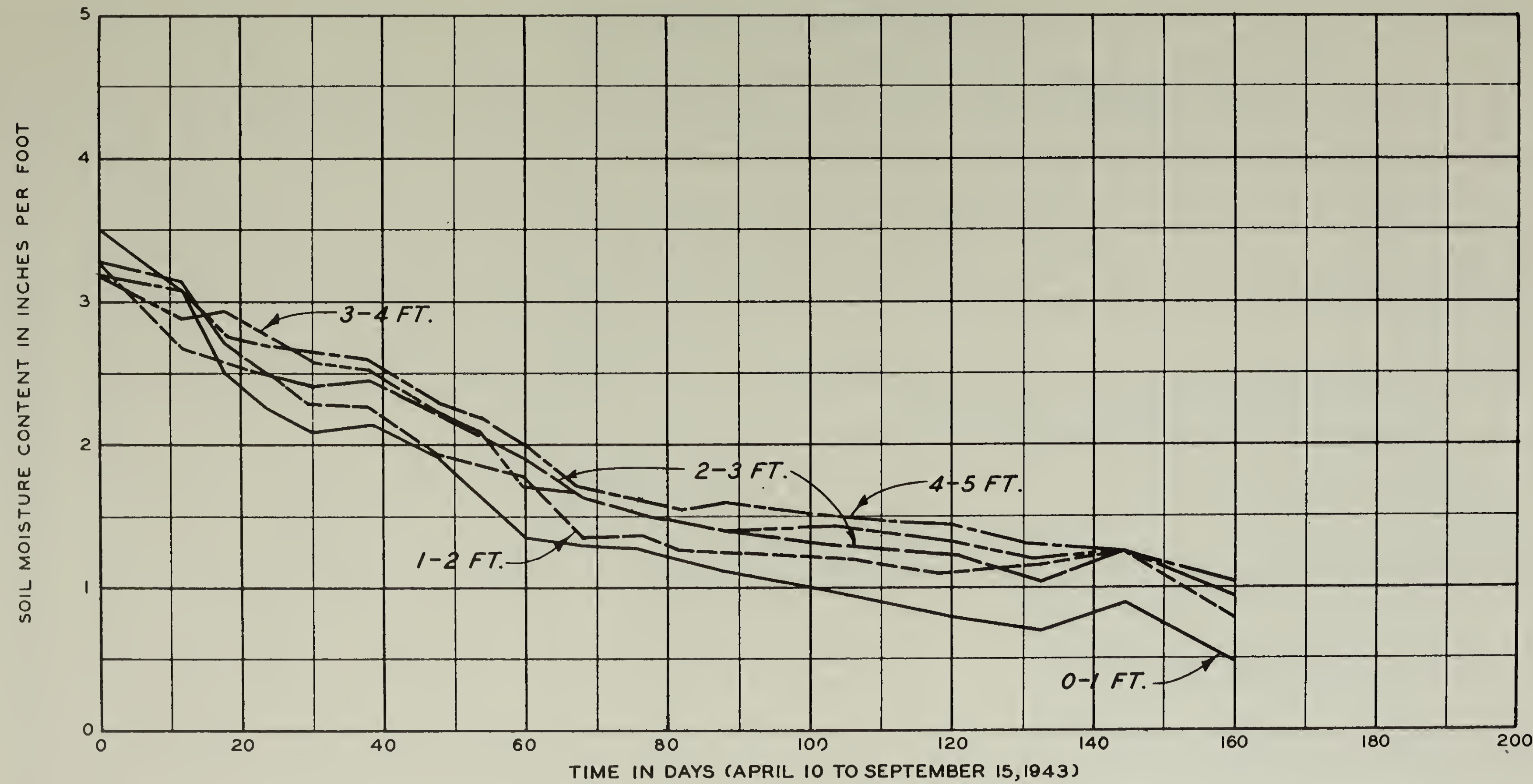

FIGURE 40. SOIL MOISTURE DEPLETION CURVES FOR SANDY CLAY LOAM WITH MIXED CHAPARRAL COVER
[FROM ROWE AND COLMAN (9)]

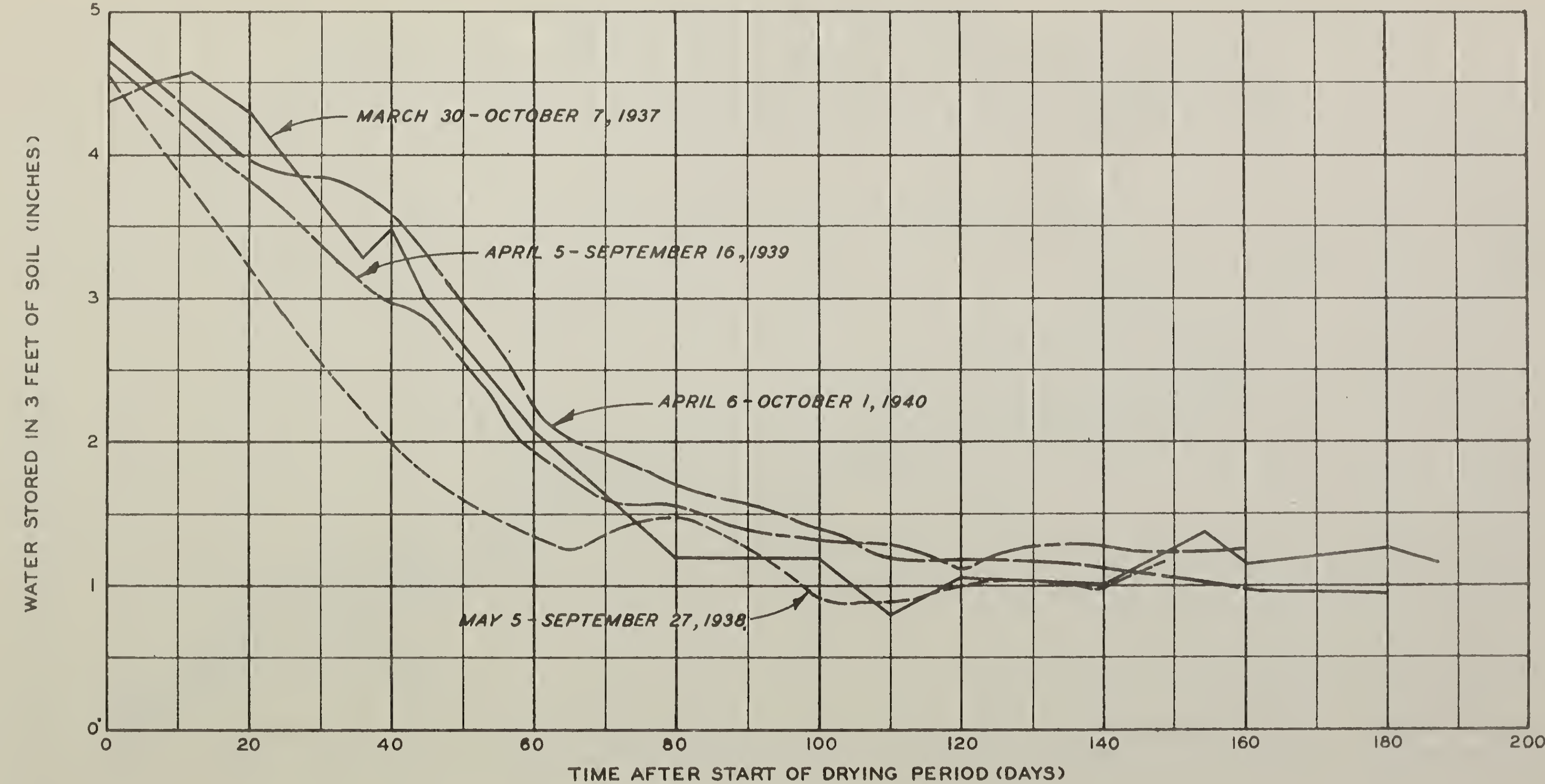

FIGURE 41. SOIL MOISTURE DEPLETION CURVES FOR SANDY CLAY LOAM UNDER WOODLAND CHAPARRAL, 1937–1940
[FROM ROWE AND COLMAN (9)]

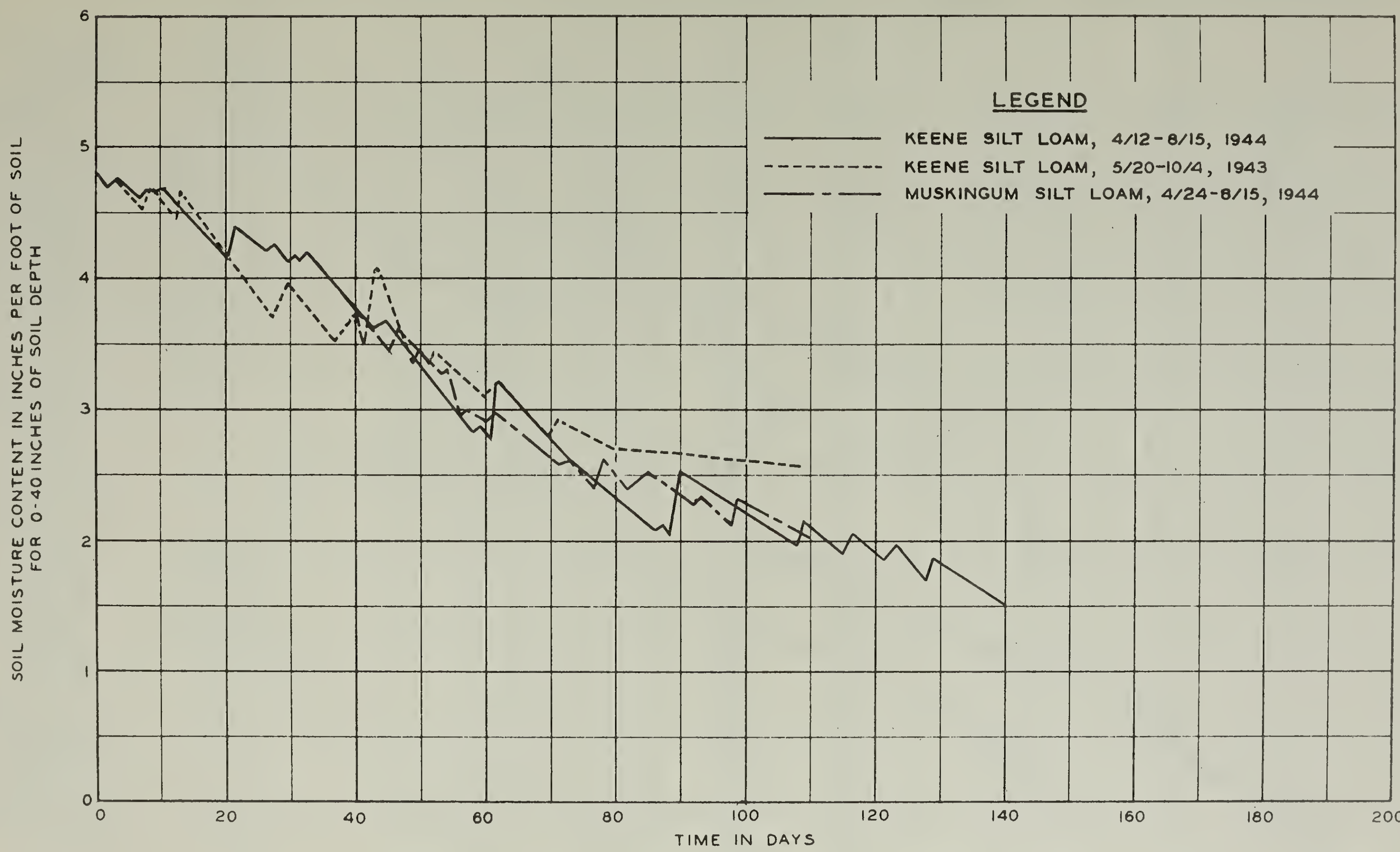

FIGURE 42. SOIL MOISTURE DEPLETION CURVES FOR SILT LOAM SOILS WITH GRASS COVER

[FROM HARROLD AND DREIBELBIS (2)]

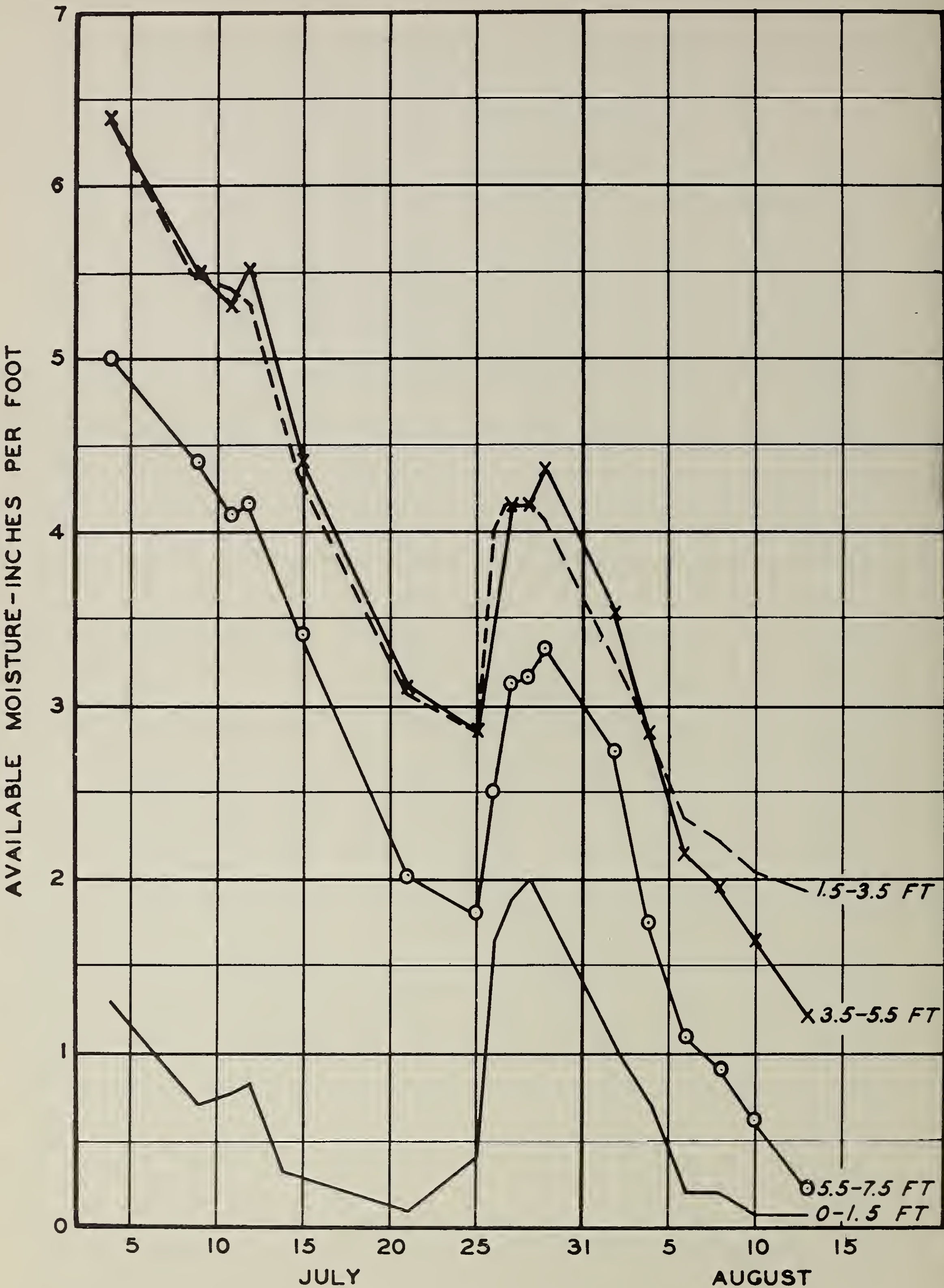

FIGURE 43. SOIL MOISTURE DEPLETION CURVES FOR SILT LOAM OVER GLACIAL TILL WITH CORN COVER [REIMANN, VAN DOREN, AND STAUFFER (8)]

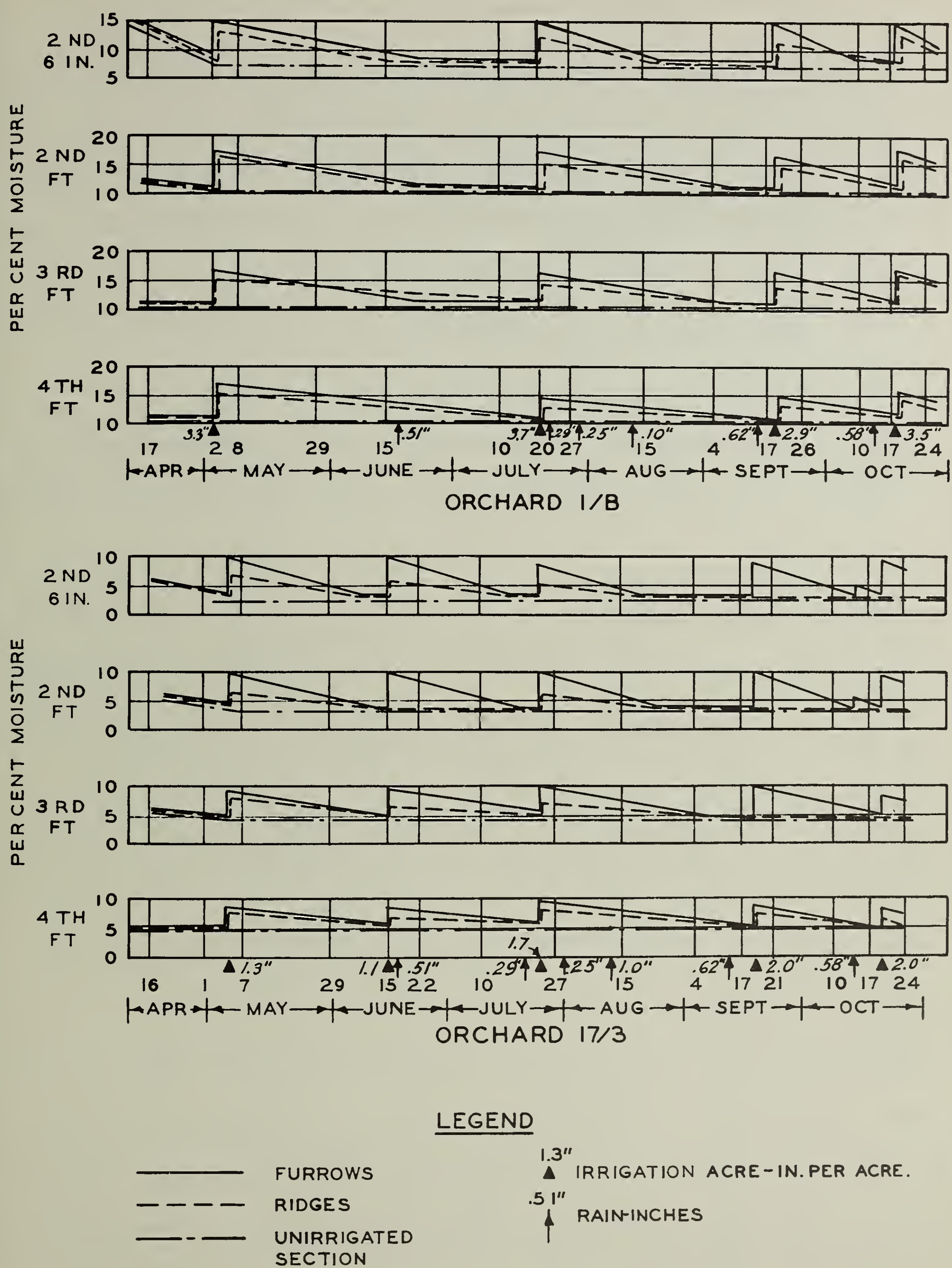

FIGURE 44. SEASONAL VARIATION IN SOIL MOISTURE CONTENTS IN ORANGE ORCHARDS (1).

both between depletion periods and depth. The soil of orchard 1/B was a sandy clay, orchard 17/3 a sandy soil. Soil moisture samples were taken immediately prior to irrigation, a few days later, and at intervals of about 3 weeks between irrigations. Trees were 12 years old and planted 25 ft apart.

Comparisons of Soil Moisture Depletion Curves

Two groups of comparisons were made of the depletion curves; the first, using the curves expressed in moisture content by weight, and the second, with those curves expressed in inches of moisture.

Figure 45 is a comparison of curves in moisture per cent taken from Figures 34, 35, and 37. These curves were selected because they appear to represent periods of depletion unbroken by rainfall. For the Vicksburg area, comparable depletion curves are given in Figure 46.

To compare rates of depletion, moisture contents at the beginning and end of 5-day periods were plotted against each other, Figures 47 and 48. The horizontal deviation from the 45° line of any point in these figures is a direct measure of the depletion occurring. Note that each plotting tends to be linear in shape. Figures 47 and 48 show the close agreement in placement of the curves for the Vicksburg and West Coast areas. The placement of the curves obviously depends on their moisture contents at saturation and wilting points, the latter point falling on or very close to the 45° line.

Soil moisture depletion curves in inches of moisture per foot of soil for 5 areas are given in Figure 49. Comparable curves for the Vicksburg sites are shown in Figure 50. Plotting by 5-day intervals, as in the

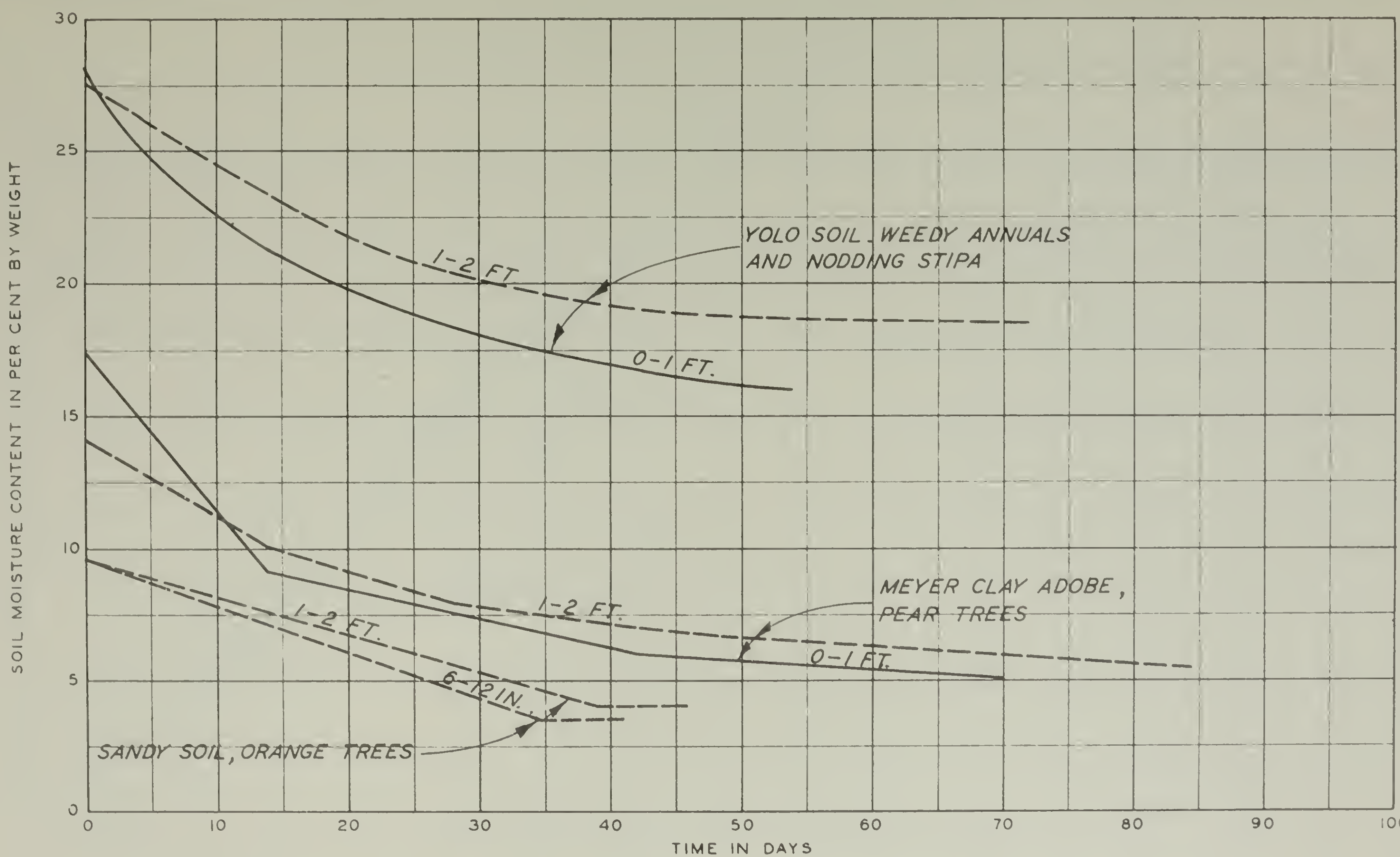

FIGURE 45. SOIL MOISTURE DEPLETION CURVES COMPARING TWO AREAS ON THE WEST COAST

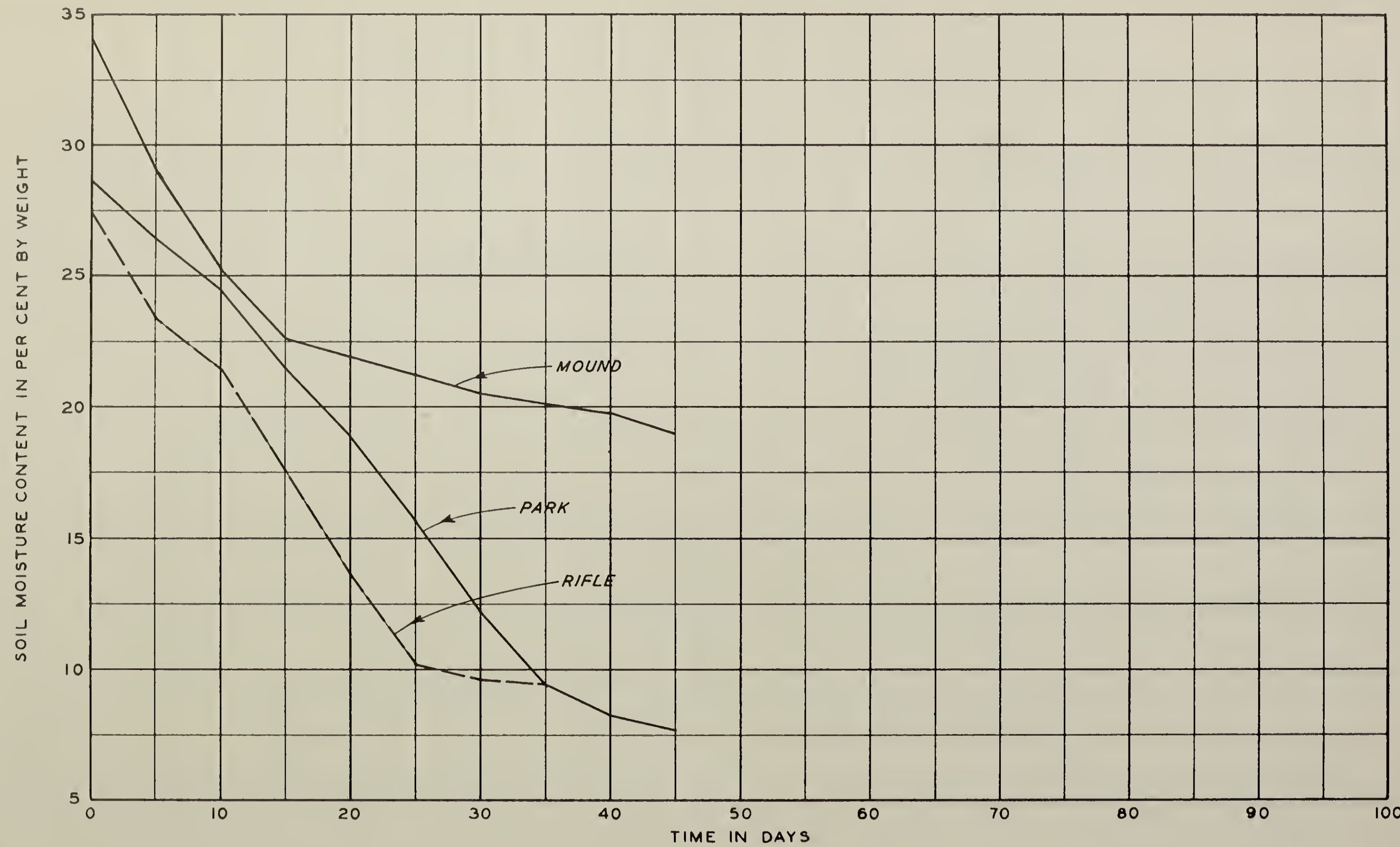

FIGURE 46. SOIL MOISTURE DEPLETION CURVES FOR SOILS OF THE VICKSBURG SITES, 6-9 INCHES DEPTH

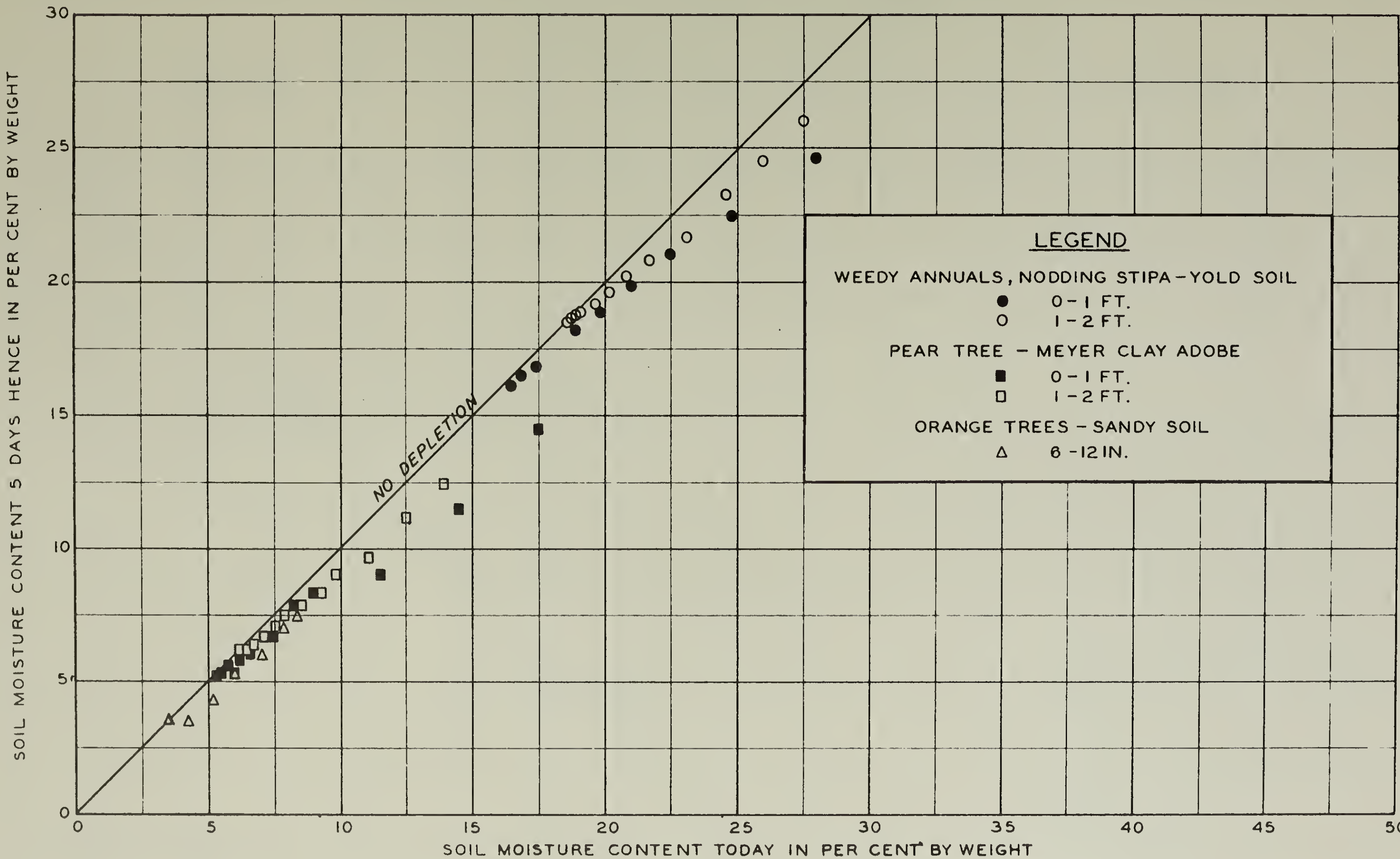

FIGURE 47. RELATION BETWEEN PERCENTAGE MOISTURE CONTENT TODAY AND FIVE DAYS HENCE

(PLOTTED FROM WEST COAST DEPLETION CURVES)

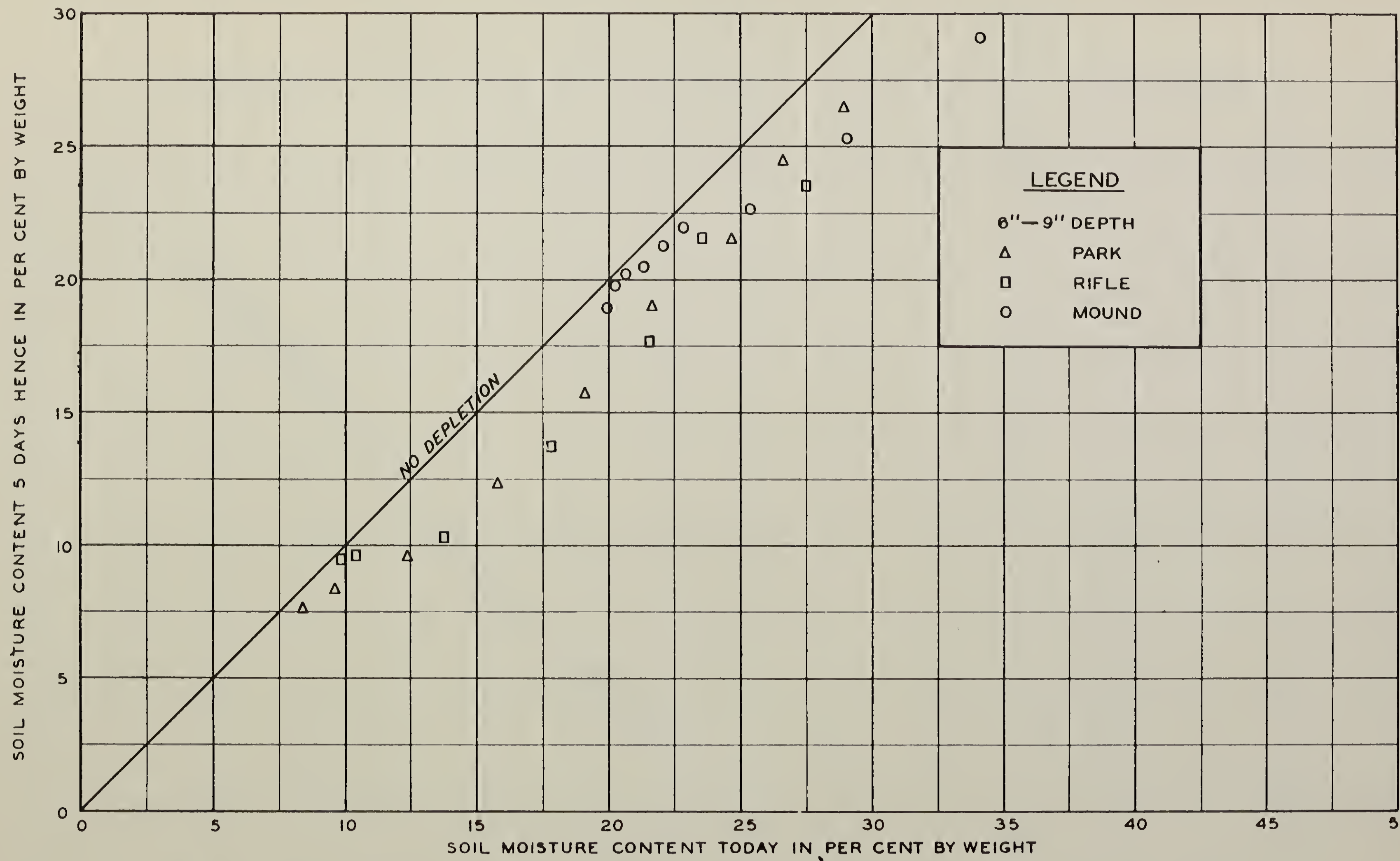

FIGURE 48. RELATION BETWEEN PERCENTAGE MOISTURE CONTENT TODAY AND FIVE DAYS HENCE

(PLOTTED FROM VICKSBURG DEPLETION CURVES)

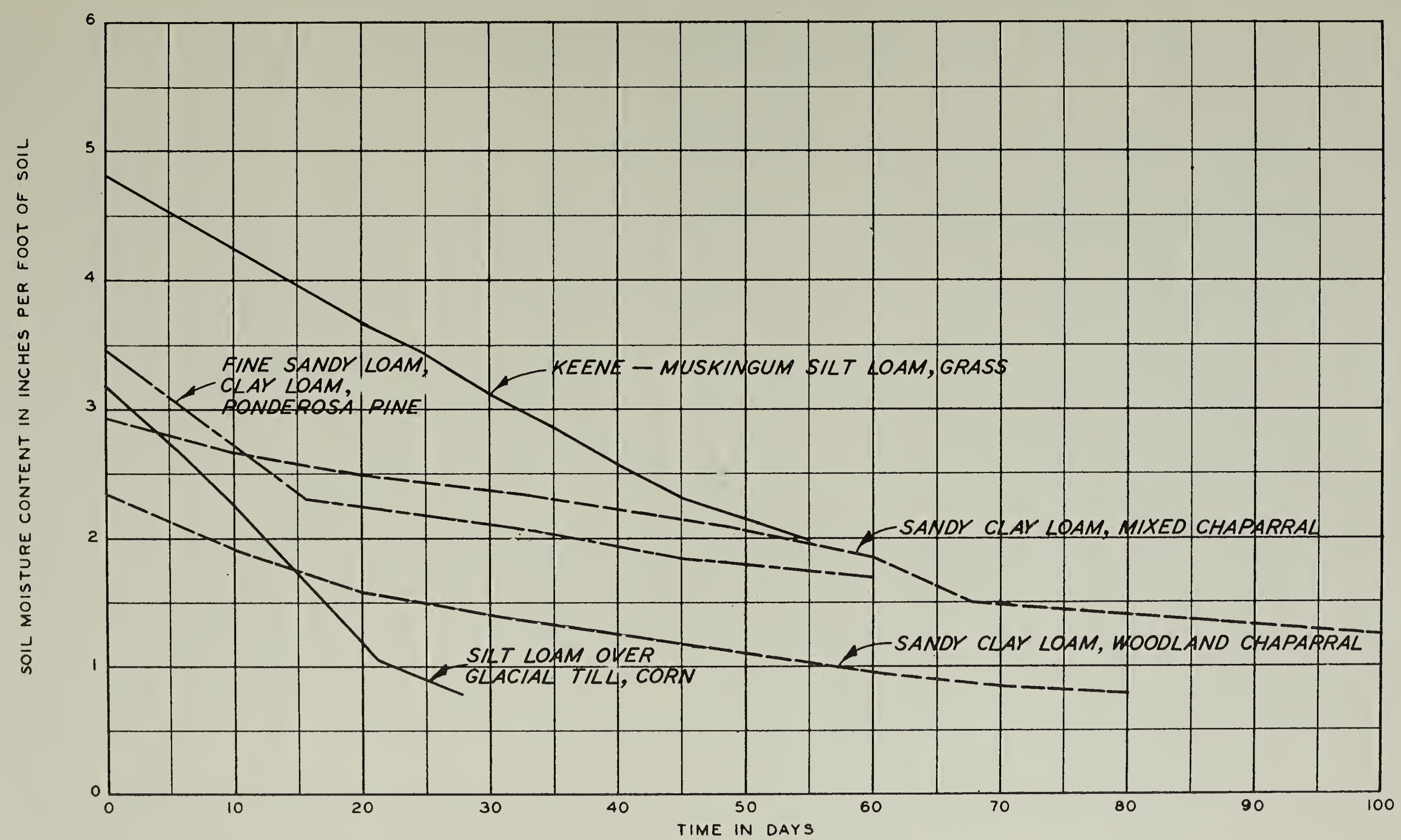

FIGURE 49. COMPARSION OF AVERAGE SOIL MOISTURE DEPLETION CURVES FOR FIVE AREAS

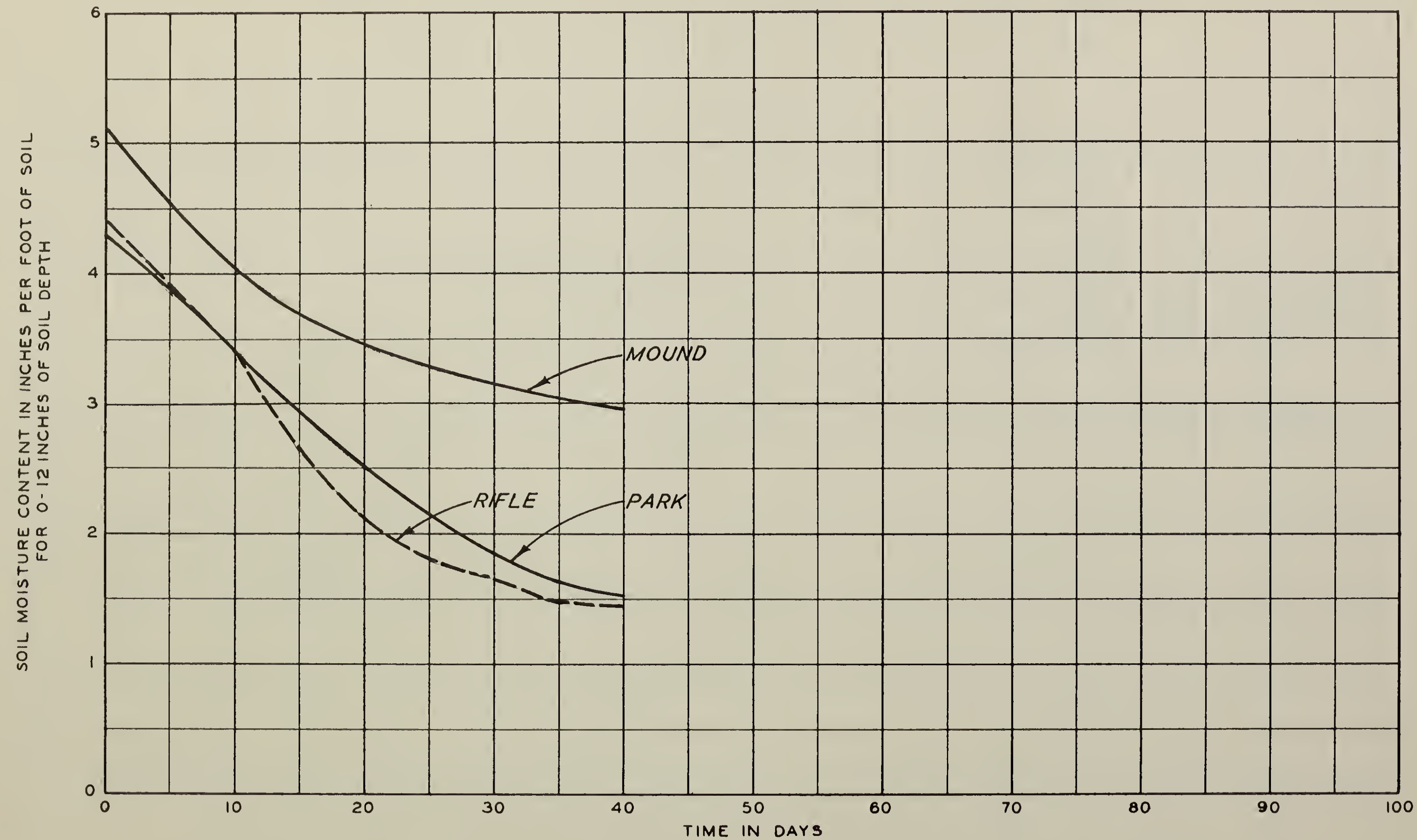

FIGURE 50. SOIL MOISTURE DEPLETION CURVES FOR SOILS OF THE VICKSBURG SITES 0-12 INCHES DEPTH

above, gives the linear relation shown in Figures 51 and 52. By overlying these figures, similarities in their relationship are quite evident for the California, Ohio, Illinois, and Vicksburg curves.

Fitting straight lines through each depletion curve gives the relationship shown in Figures 53 and 54. Those curves which do not return to the 45° line never reached wilting point, as is evident by referring to the original depletion curve in Figure 49.

These figures suggest the possibility of predicting soil moisture depletion for vegetated areas on the basis of three known soil moisture contents: field capacity, moisture content after 5 days of drying from field capacity, and wilting point. Connecting the point established from the first two moisture contents with the wilting point value, plotted on the 45° line, may give an approximation of the depletion curve.

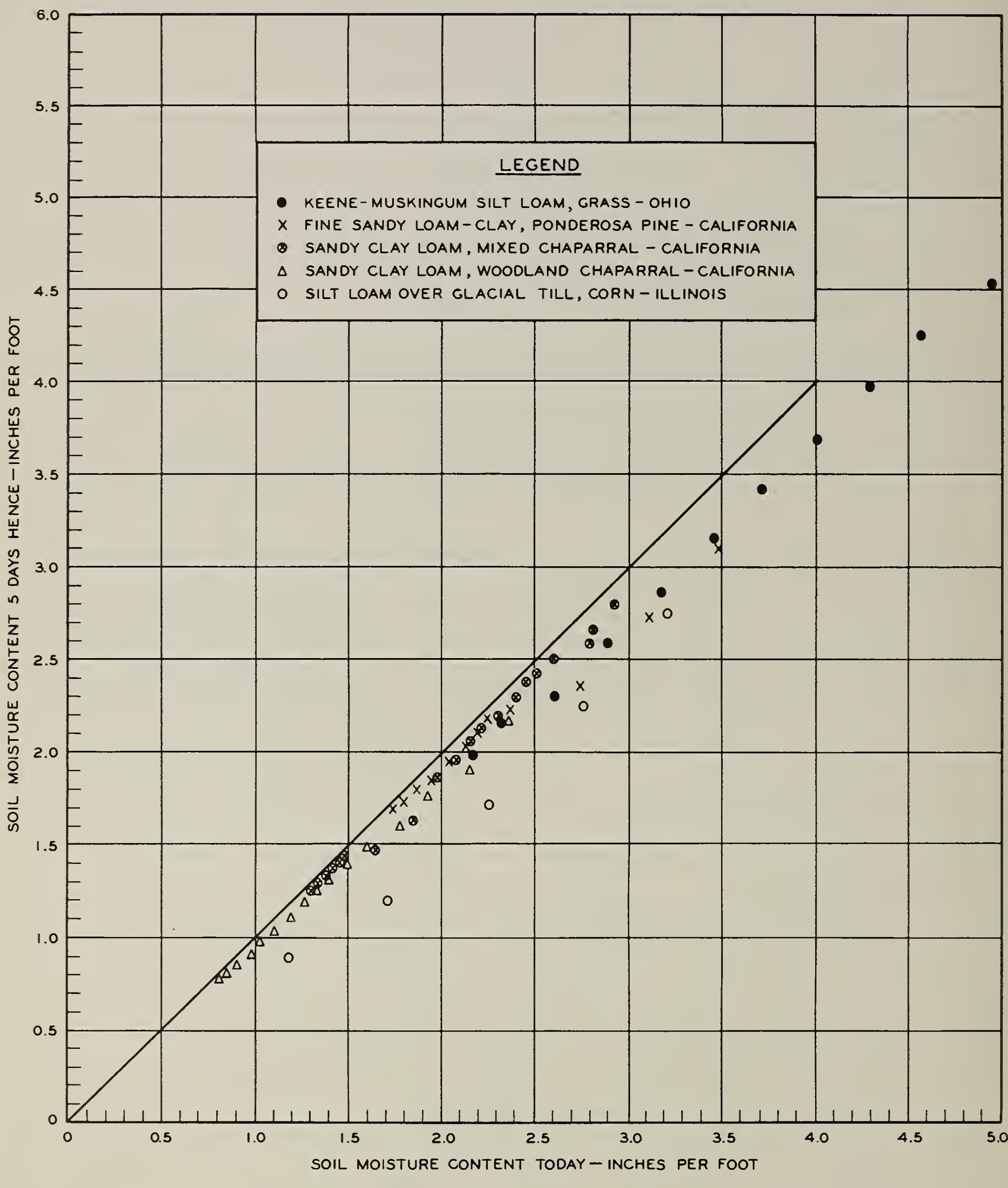

FIGURE 51. RELATION BETWEEN MOISTURE CONTENT IN INCHES TODAY AND FIVE DAYS HENCE

(PLOTTED FROM DEPLETION CURVES FOR FIVE AREAS)

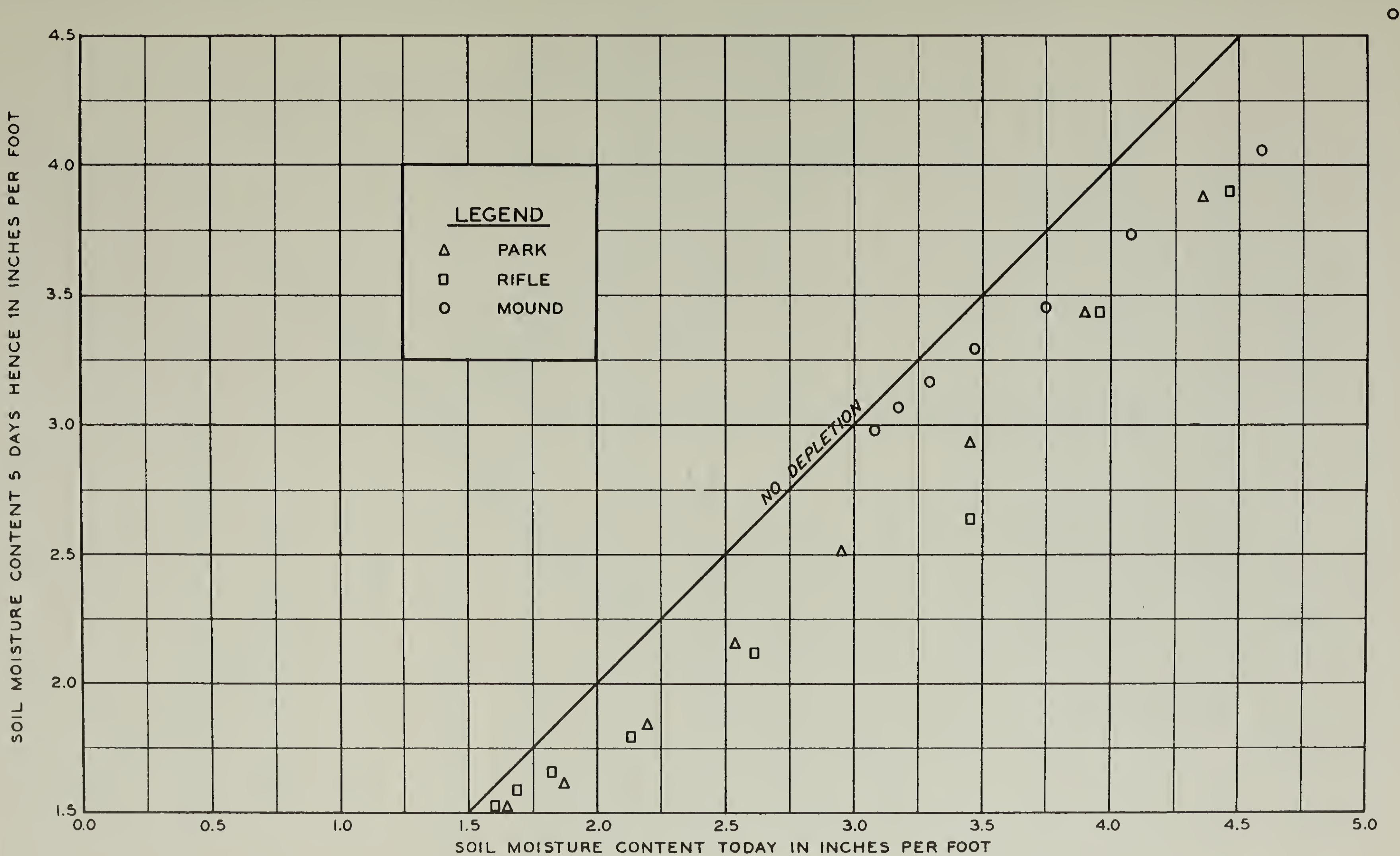

FIGURE 52. RELATION BETWEEN PERCENTAGE MOISTURE CONTENT TODAY AND FIVE DAYS HENCE

(PLOTTED FROM VICKSBURG DEPLETION CURVES)

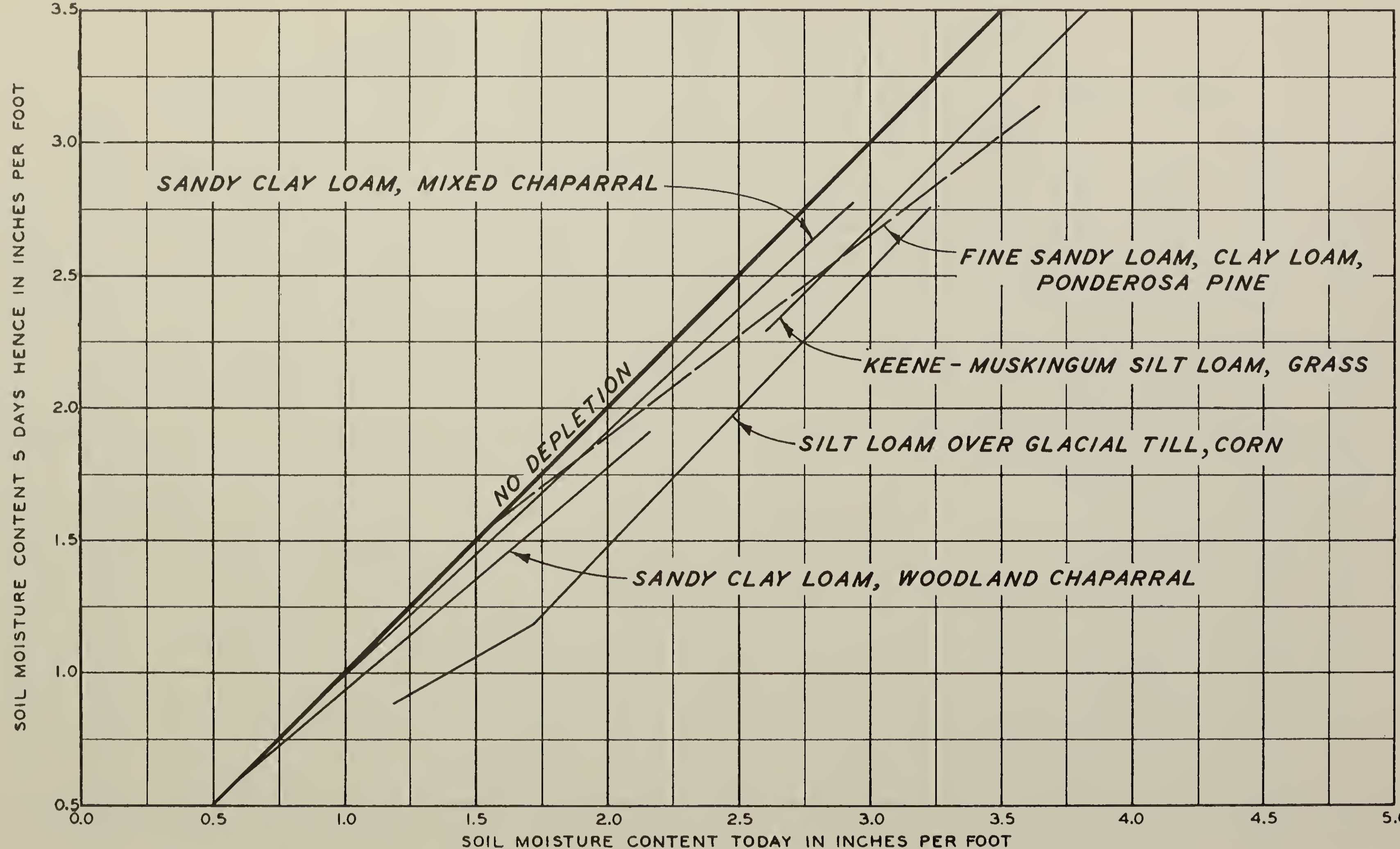

FIGURE 53. APPROXIMATE LINEAR RELATION BETWEEN MOISTURE CONTENT IN INCHES TODAY AND FIVE DAYS HENCE

(PLOTTED FROM DEPLETION CURVES FROM FIVE AREAS)

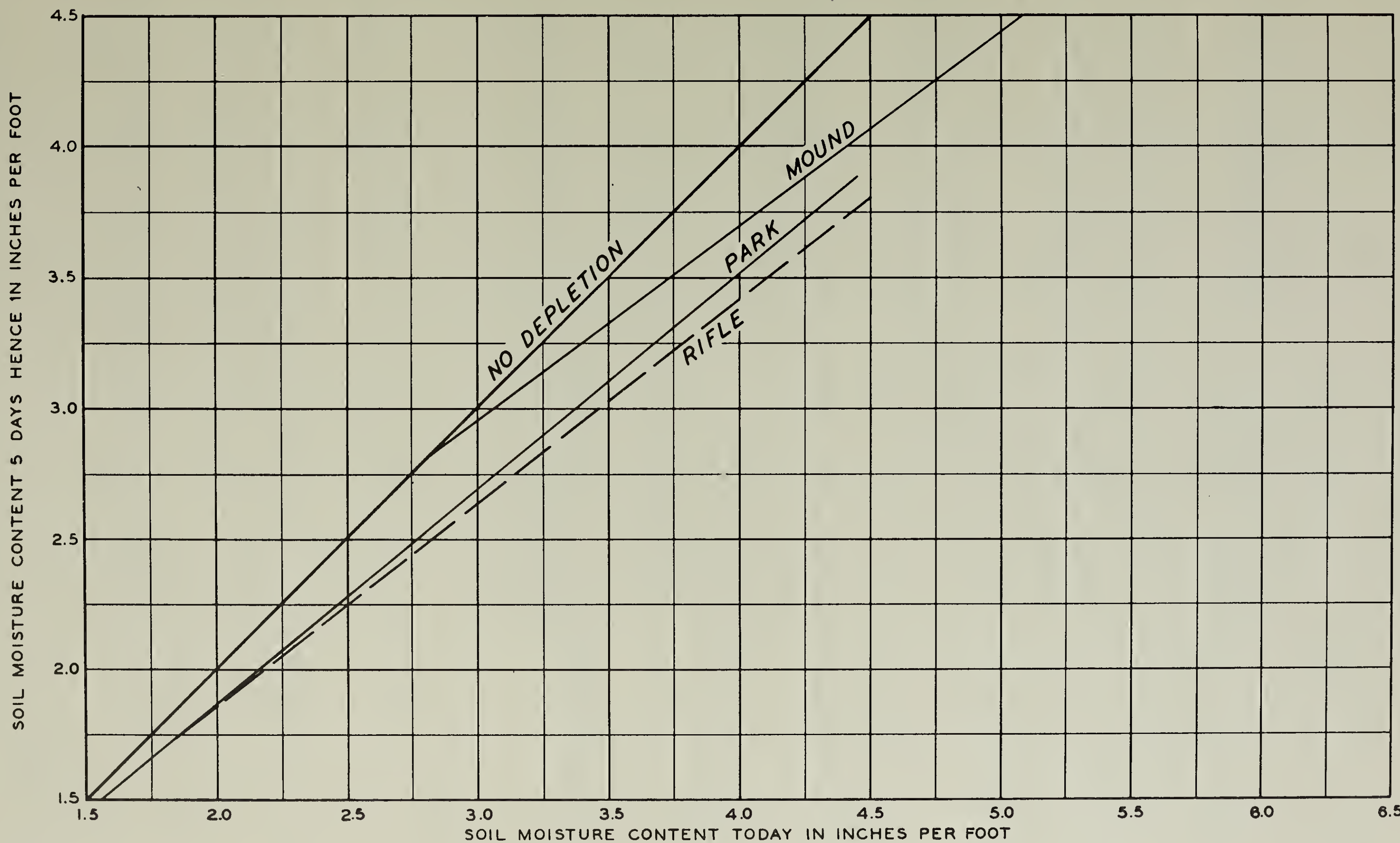

FIGURE 54. APPROXIMATE LINEAR RELATION BETWEEN MOISTURE CONTENT IN INCHES TODAY AND FIVE DAYS HENCE

(PLOTTED FROM VICKSBURG DEPLETION CURVES)

Literature Cited

1. Esselen, D. J.,
1937. Citrus irrigation practices. Union of South Africa, Department of Agriculture and Forestry, Science Bulletin 159.

2. Harrold, L. L., and Dreibelbis, F. R.,
1945. An accounting of the daily accretion, depletion and storage of soil water as determined by weighing monolith lysimeters. Trans. Amer. Geophys. Union, 26 (2): 283-292.

3. Hendrickson, A. H., and Veihmeyer, F. J.,
1945. Permanent wilting percentage of soil obtained from field and laboratory trials. Plant Physiol. 20:517-539.

4. Henrici, M.,
1946. The transpiration of different plant association in South Africa. Union S. Africa, Dept. of Agr., Forest Service Bulletin 244.

5. Kramer, Paul J.,
1949. Plant and soil water relationships. New York, McGraw-Hill Book Company, Inc.

6. Lassen, Leon; Lull, Howard W., and Frank, Bernard,
1951 Some fundamental plant-soil-water relations in watershed management. Forest Service, Dept. of Agriculture.

7. Penman, H. L.,
1951. The role of vegetation in meteorology, soil mechanics, and physics. Brit. Jour. of Applied Physics 2:145-151.

8. Reimann, E. G., Van Doren, C. A., and Stauffer, R. S.,
1945. Soil moisture relationships during crop production. Soil Sc. Soc. of Amer. Proc. 10:41-46.

9. Rowe, P. B., and Colman, E. A.,
1951. Disposition of rainfall in two mountain areas of California. Tech. Bulletin 1048, Department of Agriculture.

10. Russel, E. John,
1950. Soil conditions and plant growth. Longmans, Green and Co.

11. Schneider, G. William, and Childers, N. F., 1941. Influence of soil moisture on photosynthesis, respiration, and transpiration of apple leaves. Plant. Physiol., 16:565-583.

12. Thornthwaite, C. W., 1948. An approach toward a rational classification of climate. Geo. Review, 38 (1):55-94

13. Thornthwaite, C. W., Undated. Climate and soil moisture. Unpublished report.

14. Veihmeyer, F. J., and Hendrickson, A. H., 1948. The permanent wilting percentage as a reference for the measurement of soil moisture. Trans. Amer. Geophys. Union, 29 (6):887-891.

15. Wadleigh, C. H., and Gauch, H. G., 1946. Growth and rubber accumulation in Guayule as conditioned by soil salinity and irrigation regime. U. S. Dept. Agr. Tech. Bulletin 925.

16. Wadleigh, C. H., 1946. The integrated soil moisture stress upon a root system in a large container of saline soil. Soil Sci. 61:225-238.

17. Work, R. A., and Lewis, M. R., 1936. The relation of soil moisture to pear tree wilting in a heavy clay soil. Jour. Amer. Soc. Agron., 28:124-136.

REVIEW OF SPECIAL STUDIES

To facilitate the measurement of soil moisture and to evaluate the soil moisture record it has been necessary to devote some effort to special studies. From these studies have come the development of instruments to provide more accurate records of soil moisture and fundamental information which is basic to an understanding of procedures used or results obtained.

The results of six of these studies are briefly described. Detailed reports have been prepared for each and can be made available on request.

Development of Instrumentation

One of the problems encountered in the use of electrical soil moisture units is their installation in the soil with a minimum of soil disturbance. The greater the soil disturbance, the more chance of creating in the soil surrounding the units disturbed conditions which will affect soil water movement and storage, and consequently the soil moisture record. To keep disturbances to a minimum, soil moisture units are now installed in the side of auger holes about 5-in. in diameter rather than directly in the hole or in the face of pits. This required first, however, the development of an instrument which could be lowered into the hole to insert the units.

The inserter developed for this operation is shown in Figure 55. It works on the principle of a scissor-jack; turning the handle on top forces the hinges together which in turn pushes the unit into the sidewall of the auger hole. The handle can be made as long as desired.

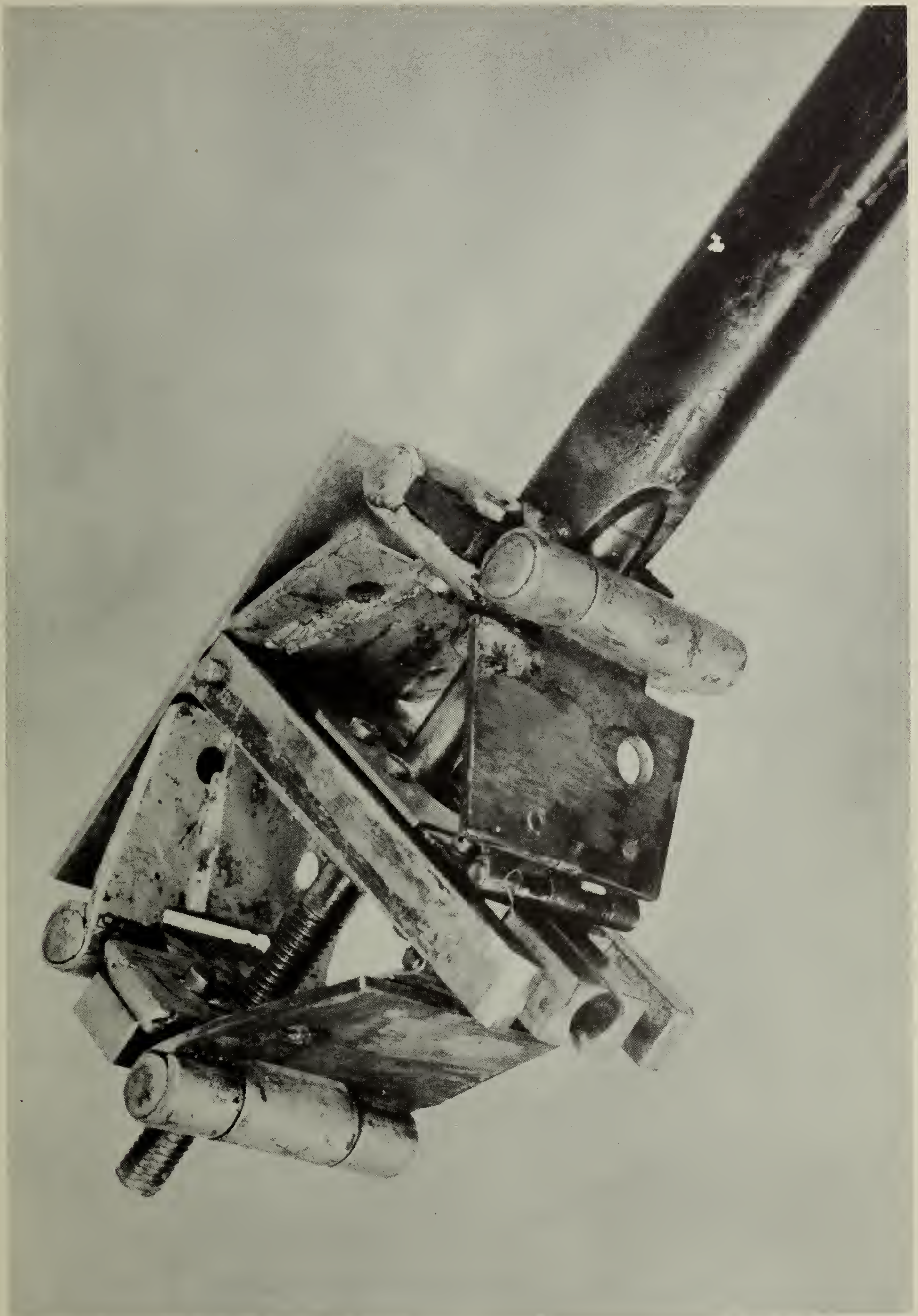

Figure 55. Unit inserter

Besides giving a minimum of soil disturbance, use of the auger-hole method and inserter considerably speeds up the installation of units. With the inserter two men can install a tier of 10 units in half a day.

A second problem requiring solution was the wetting of switches to which the soil moisture units are connected, with consequent loss or error in soil moisture readings. To overcome this a waterproof case of Plexiglas plastic was developed for the switch. By inserting the switch into a tube of this material, sealing the ends of the tube with Plexiglas discs, and making all openings for passage of wires waterproof, a case is provided which has worked successfully for the past several months.

The case was mounted on a wooden stand designed to facilitate readings. Figure 56 shows this installation.

Equilibration During Laboratory Calibration

During the first six months of the project considerable time and thought were given to the laboratory calibration of the Colman units with the hope that calibration curves developed in the laboratory would be applicable to field conditions. Later experience showed that field and laboratory calibrations were not equivalent. However, laboratory curves have been helpful in describing the general shape of the ohms resistance-moisture content relation and fixing the wet and dry ends of the curve.

One of the procedures in laboratory calibration of units has been the use of a humid chamber to allow the moisture in the soil core around the unit to come to an equilibrium between drying periods. Supposedly, during drying, a moisture gradient would be established in the core which would affect the resistance readings; placing the core-unit in a humid

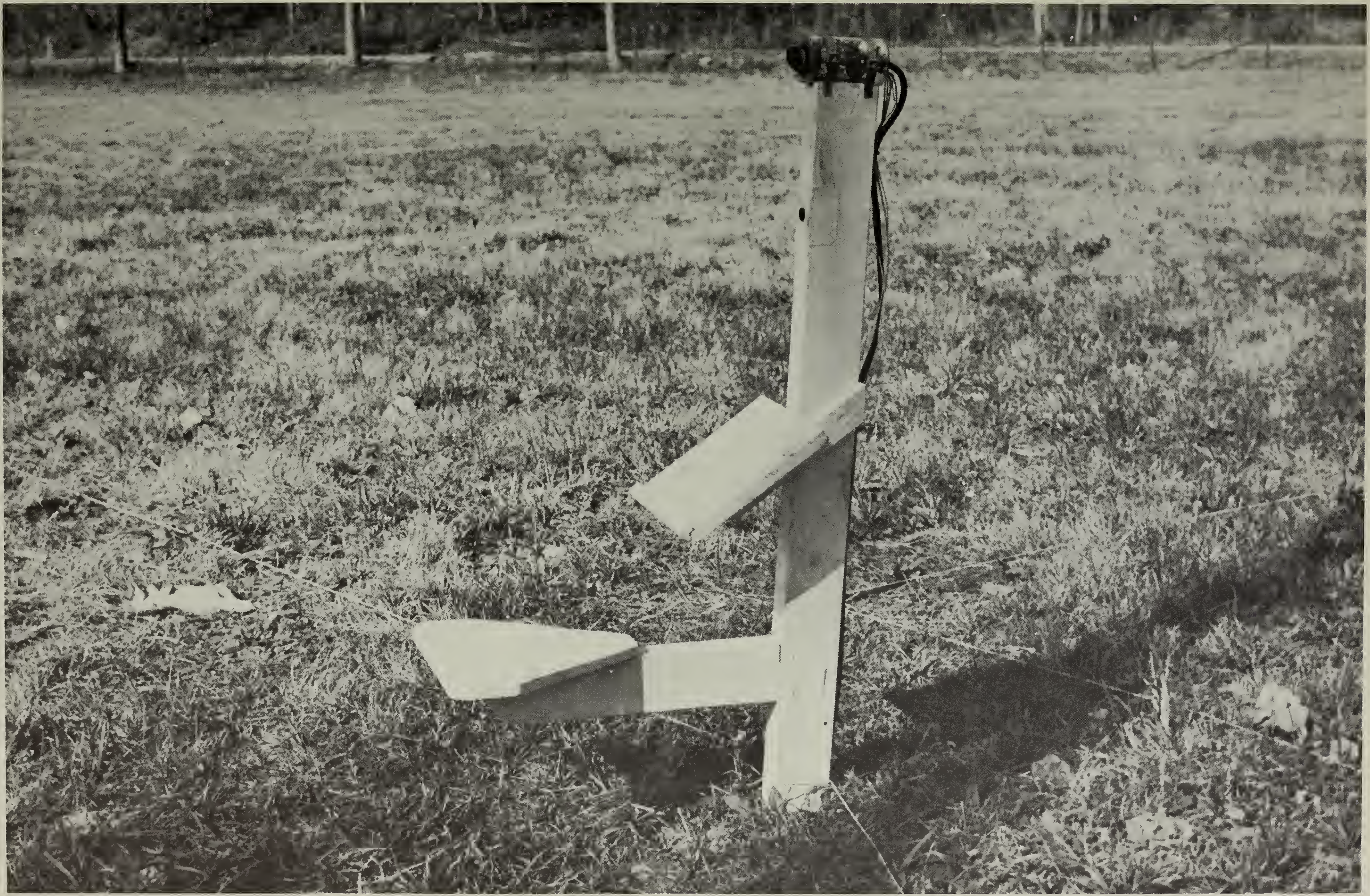

Figure 56. Waterproof case for switch

chamber overnight would reduce or remove the gradient so that a resistance measurement would reflect soil moisture content of the entire core.

During laboratory calibration there was some question as to whether the gradient was actually being reduced in the chamber. To answer this, core-units were left in the chamber for a period of several days, and resistance read periodically. Also, core-units were weighed and resistance measured before and after the humid chamber treatment. Finally, after an equilibration period, soil cores were sectioned and moisture content of each section determined to get a measure of the gradient.

Results showed that equilibration in the humid chamber was not occurring. Instead there was a steady loss of soil moisture and increase of resistance. The sectioned cores also showed that a moisture gradient still existed following the humid chamber treatment. Figure 57 shows the gradients, both in moisture content and resistance, throughout the soil core.

From this study it is apparent that the humid chamber treatment is not required in humid climates such as at Vicksburg and, therefore, in future laboratory calibration considerable time can be saved by eliminating this procedure. This study also gives an insight into the difference between drying under laboratory and field conditions, a difference due to the fairly uniform drying that occurs in the field by the root system, and the nonuniform drying that occurs in the laboratory by evaporation acting inward from the surface of the core. This may be a factor causing some of the differences found between laboratory and field calibration curves.

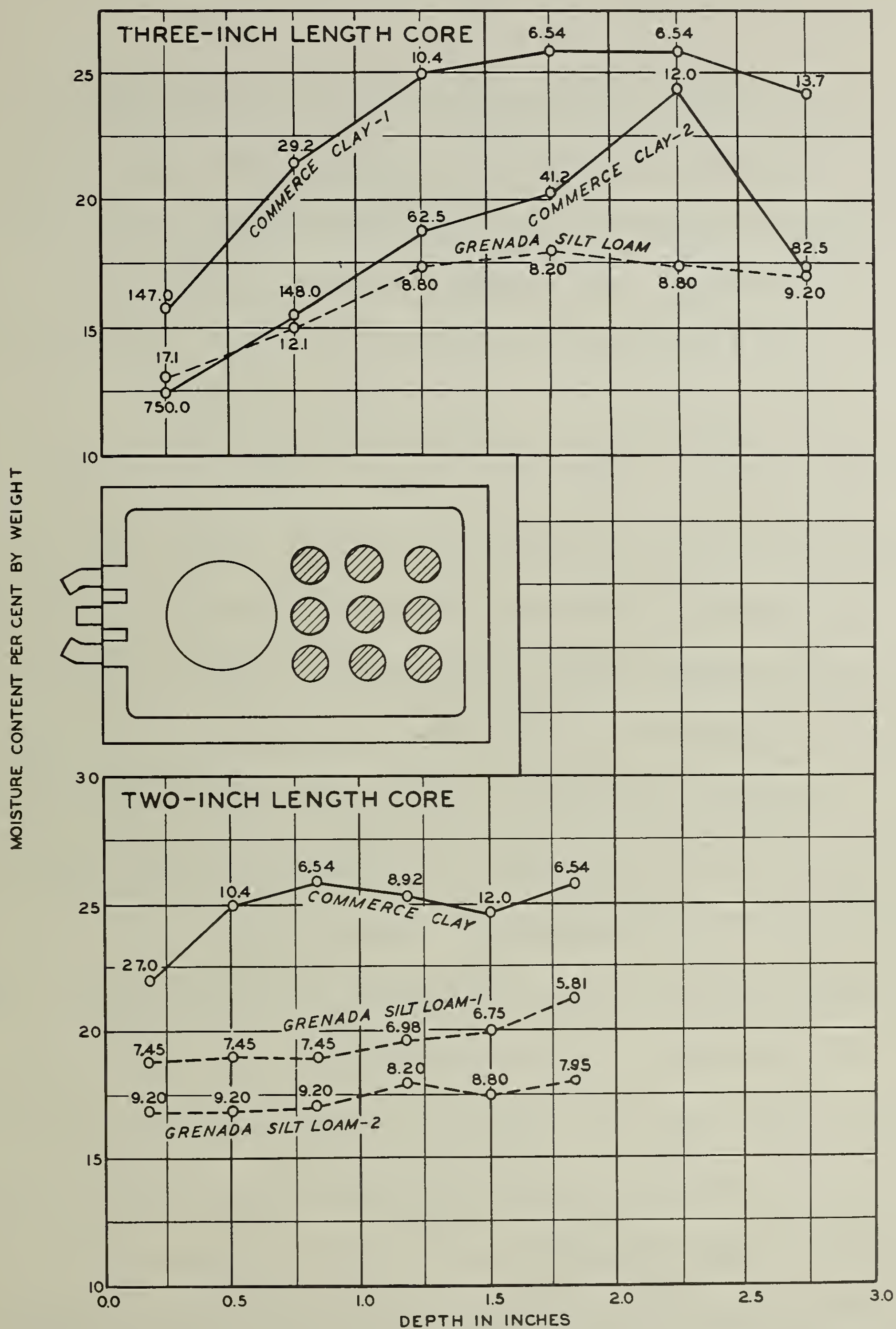

FIGURE 57. VARIATION OF MOISTURE CONTENT AND UNIT RESISTANCE BY DEPTH WITHIN SOIL CORES AFTER AN OVER-NIGHT EQUILIBRATION
(UNIT RESISTANCE IN KILOHMS INDICATED)

Comparison of Bulk Density Sampling Procedures

Conversion of soil moisture data in per cent by weight to inches of water requires determination of bulk density of the soil. As described in Progress Report I, Appendix H, considerable time and thought were given to these determinations for, in order to evaluate and predict the effect of rainfall on soil moisture, an accurate comparison is required of soil moisture accretion in inches to corresponding rainfall.

Bulk densities for the summer data were obtained primarily by the block method, described in Appendix H, by 3-in. depths from 0 to 15 in. Time and labor were not available, however, to obtain bulk densities for the lower depths by this method. Consequently, the San Dimas soil core sampling tube, developed at the California Forest and Range Experiment Station, was used at lower depths. At the same time, core samples were taken throughout the 0-15-in. depth to compare with those taken by the block method earlier in the year.

The comparison showed some difference in bulk densities, with cores from the tube tending to be higher, at any one moisture content, than those obtained with the block method. A second more exact comparison was made at Rifle with adjacent samples taken by the two methods at the same time. Table 24 gives the results.

Considering moisture differences, bulk densities by the two methods agree fairly well at the two lower depths. At the 0-9-in. depth, values from the core sampler are again higher, indicating some compression. To determine the effect of the two methods of sampling on soil structure, an aggregate analysis was made on samples by sieving water-stable aggregates

Table 24

BULK DENSITY OF RIFLE SITE SOIL

Comparison of Block and San Dimas Techniques

	San Dimas (Avg of Four)		Block	
Depth In.	Bulk Density	Per Cent Moisture	Bulk Density	Per Cent Moisture
0-3	1.341	32.6	1.175	35.2
3-6	1.435	27.8	1.346	30.2
6-9	1.512	25.6	1.443	24.6
9-12	1.577	24.4	1.575	23.1
12-15	1.534	26.4	1.594	23.6
15-18	1.502	27.0	1.589	24.2
18-21	1.484	28.4	1.550	23.6
21-24	1.462	29.6	1.407	30.0

into five size classes. Percentages of aggregates were calculated on two bases. In the first, percentages were based on total sample weight. Since the material on the 12.7-mm sieve could be considered as fragments not broken down to water-stable aggregates, a second computation was made considering the total sample weight as only that material passing through the 12.7-mm sieve. Results are shown in Table 25. With either method of computation, less material occurred in the class of largest aggregate when using the San Dimas sampler. More material passes through the 0.295-mm sieve from the San Dimas clods. No appreciable change occurs in the amount of aggregates from 0.295 to 1.41 mm. These results indicate that stresses from the core sampler disrupt the soil structure in the core,

Table 25

RIFLE AGGREGATE ANALYSES

Comparison of Aggregate Distribution from San Dimas Sampler with Block Technique

(Average of Duplicates)

	Aggregate Size									
	>12.7 mm		1.41-12.7 mm		.59-1.41 mm		.295-.59 mm		<.295 mm	
Depth	San Dimas	Block	San Dimas	Block	San Dimas	Block	San Dimas	Block	San Dimas	Block
	Percentage by Weight of Total Sample									
0-3	48.3	30.6	5.8	14.4	2.0	5.6	1.0	3.2	43.0	46.2
3-6	22.2	9.8	14.4	26.6	5.2	8.4	1.8	2.6	56.5	52.6
6-9	4.1	20.6	27.4	39.9	10.7	13.2	4.2	3.2	53.6	23.2
9-12	28.2	62.0	42.0	25.2	5.4	3.0	2.0	0.7	22.4	9.6
12-15	58.8	73.6	23.4	16.0	2.4	1.6	0.8	0.3	14.6	8.6
15-18	3.6	72.1	43.0	16.3	11.4	2.2	3.9	0.6	38.1	8.3
18-21	13.8	48.7	32.0	29.2	5.4	2.6	2.2	0.6	46.6	18.8
21-24	16.3	30.2	28.4	25.4	6.6	5.9	2.1	1.8	46.5	36.8
Avg	24.4	43.4	27.0	24.1	6.1	5.3	2.2	1.6	40.2	25.5
	Percentage by Weight of Sample Through 12.7-mm Sieve									
0-3			10.6	21.8	3.8	8.1	1.7	4.6	83.9	66.6
3-6			19.0	29.6	6.5	9.3	2.2	2.8	72.2	58.3
6-9			28.5	50.4	11.2	16.4	4.4	4.0	56.0	29.2
9-12			58.8	62.3	7.3	7.8	2.7	1.9	31.2	28.1
12-15			55.2	60.0	5.3	6.1	1.8	1.2	37.6	32.8
15-18			44.6	59.0	11.9	7.7	4.1	2.3	39.4	32.0
18-21			36.2	49.0	6.4	4.8	2.6	1.4	54.7	44.8
21-24			36.1	36.1	7.0	8.5	2.2	2.6	54.6	52.8
Avg			36.1	46.0	7.4	8.6	2.7	2.6	53.7	43.1

causing large aggregates to break down into very small particles. Bulk density data indicate compression of the cores at the 0-9-in. depth. This could explain the greater percentage on the 12.7-mm sieve when using the San Dimas sampler. At lower depths the bulk densities were comparable, indicating no compression.

Even with little difference in bulk density for depths below 9 in. the aggregate analysis revealed a difference in aggregate distribution. This study is too limited to draw any conclusion; however, it does pose the problem that if the core sampler affects aggregation to any extent it would probably affect the permeability of the sample. Possibly, this would affect the soil permeability determinations that are frequently made on core samples.

Relation of Bulk Density to Moisture Content

In Progress Report I, Appendix H, there is a full discussion of the relation of moisture content to bulk density for the three prediction sites. Curves describing this relation were used to convert moisture per cent to inches depth. Analysis of data obtained later with the San Dimas sampler, however, indicated that the relation was not always linear, as shown in Appendix H, but, at least for some sites and depths, tended to be curvilinear with greater rate of change in bulk density per unit change of soil moisture, at the higher moisture contents.

At Park, bulk densities for the 0-12-in. depth from San Dimas sampler were higher than those obtained by the block method at the same moisture content. From the previous study comparing bulk densities of the two methods, this was to be expected. Consequently, the bulk density-moisture content curves for Park in Progress Report I based on block data were retained. Curves for the San Dimas data for depths below 12 in. were very similar and could be expressed as one curve. The data indicated that this relation was linear. However, checking the total pore space, as calculated from the bulk density, against the volume of soil moisture for

moisture contents above 30 per cent, there was more moisture than available space. Accordingly, the bulk density at 40 per cent moisture content (saturation) was reduced so as to provide a total pore space approximately equivalent to the moisture volume and this point connected to the 30 per cent value. The resultant curve is given in Figure 58 with the curves from the other depths from the previous progress report.

For the Rifle data, the same procedure was used. Except for one instance, bulk density-moisture content curves from the block data were used for the upper depths, and the San Dimas data were used for depths below 12 in. after adjusting the volume weights at saturation to obtain agreement between pore space and moisture volume. A comparison of moisture volume and pore space for the 9-12 in. curve in Progress Report I for the pit sites, showed it to be consistently too high. Therefore the 9-12-in. relation for the tiers was substituted. The curves are shown in Figure 59.

Bulk density-moisture content curves for Mound for the 0-15-in. depth were considerably modified from those in Progress Report I. As stated in that report, bulk densities for the lower moisture contents were obtained by the paraffin method. Comparable bulk densities, using the San Dimas sampler, were much lower. This may be due to the fact that the paraffin samples were clods that did not include the normal proportion of cracks associated with this soil. Bulk densities from the paraffin data gave total porosities of only 34 to 42 per cent at low moisture contents.

Accordingly, the paraffin data were discarded and bulk density-moisture content curves were developed from the San Dimas data and the

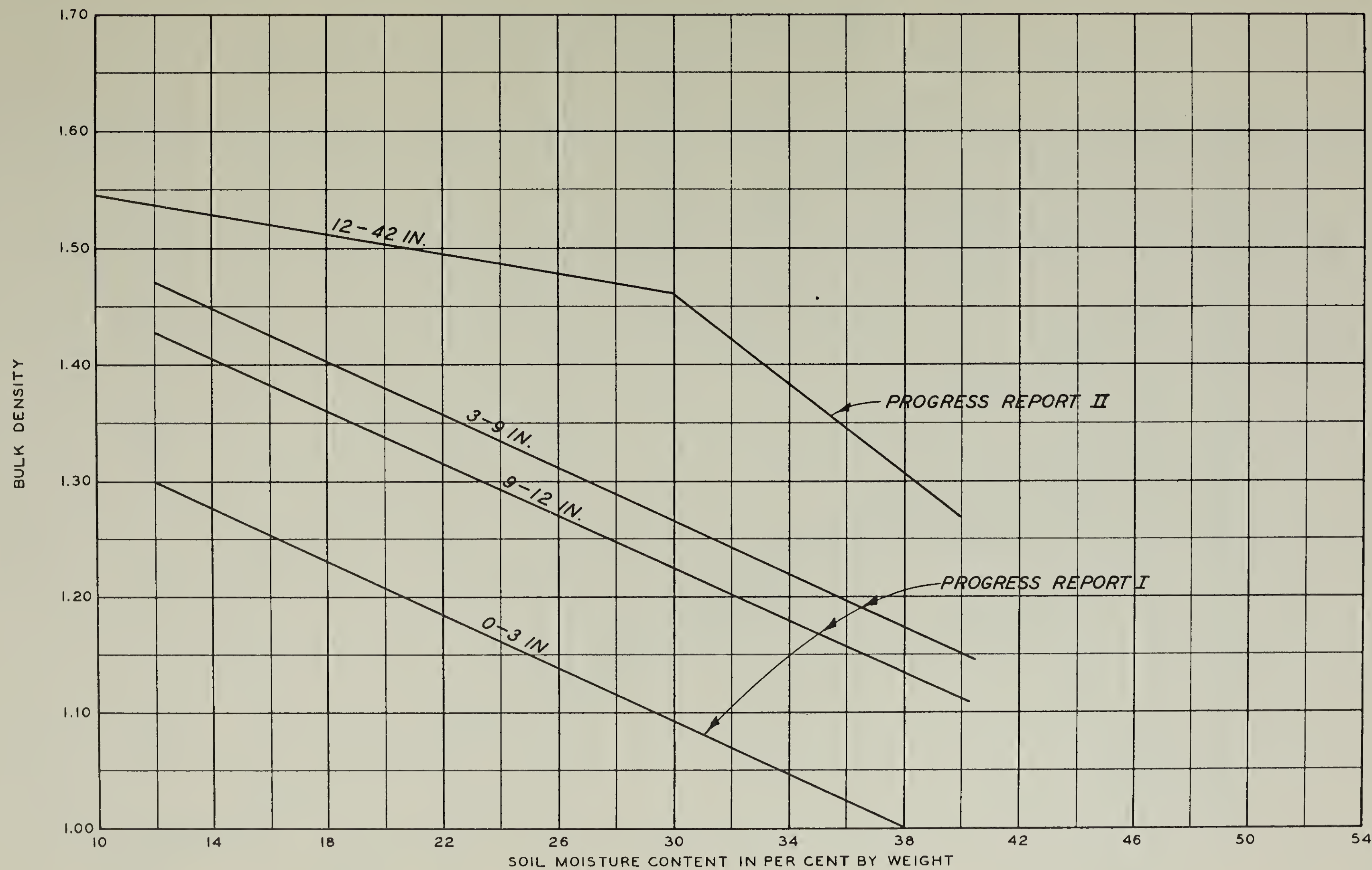

FIGURE 58. RELATION BETWEEN BULK DENSITY AND SOIL MOISTURE CONTENT

PARK SITE

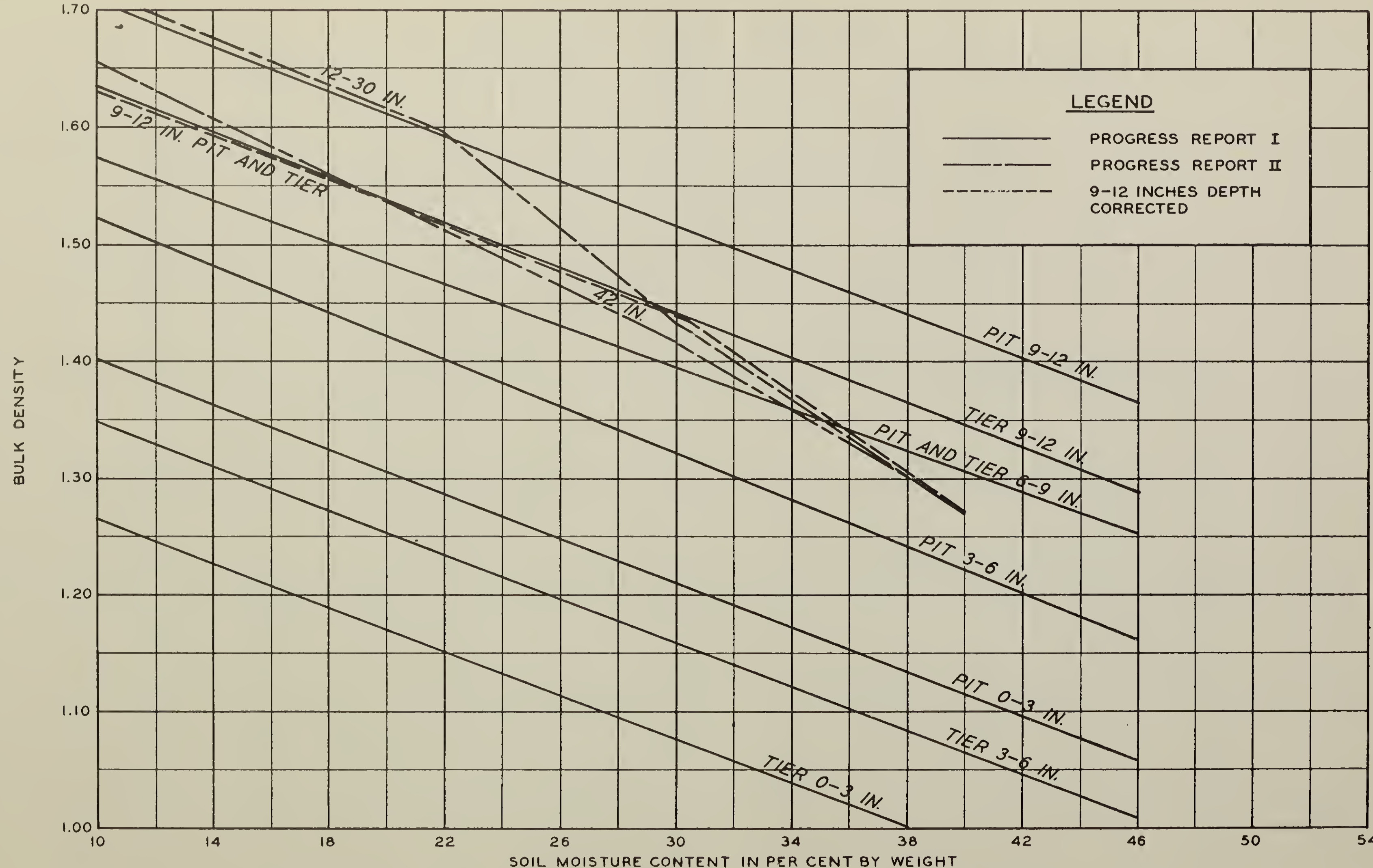

FIGURE 59. RELATION BETWEEN BULK DENSITY AND SOIL MOISTURE CONTENT

RIFLE SITE

few block data available. The corrected curves and those from Progress Report I are given in Figure 60.

Range and Stability of Colman Soil Moisture Units

The resistance of the Colman unit varies with the changes in moisture content within the Fiberglas between the electrodes. To verify the range and accuracy of units, tests were conducted in the laboratory on Fiberglas and with units in graded soil materials

Moisture tension curves of two grades of Fiberglas were determined to show the range in moisture content of the Fiberglas and thereby the working range of the unit (Figure 61). The fine woven grade corresponds with that found in the units. The great yield of moisture at low tension changes indicates that the units can detect moisture changes in soils wetter than field capacity.

In a second test, five units were calibrated in each of five separates of differing size from fine sand to silt. The separates were obtained from builder's sand and Memphis silt loam. The humus, clay, microorganisms and soluble salts were largely removed by washing, in order to test the units in a medium similar to soil in its moisture properties but without variations due to change in structure, swelling or salt content. The units were calibrated through four to five drying cycles.

Results showed a variation between units indicating the need of individual calibration, but a constancy between drying cycles pointing out stability of the units. Calibration curves of the five separates, averaging the five units and several drying cycles, are shown in Figure 62. A change in the resistance-moisture content relationship is shown as the

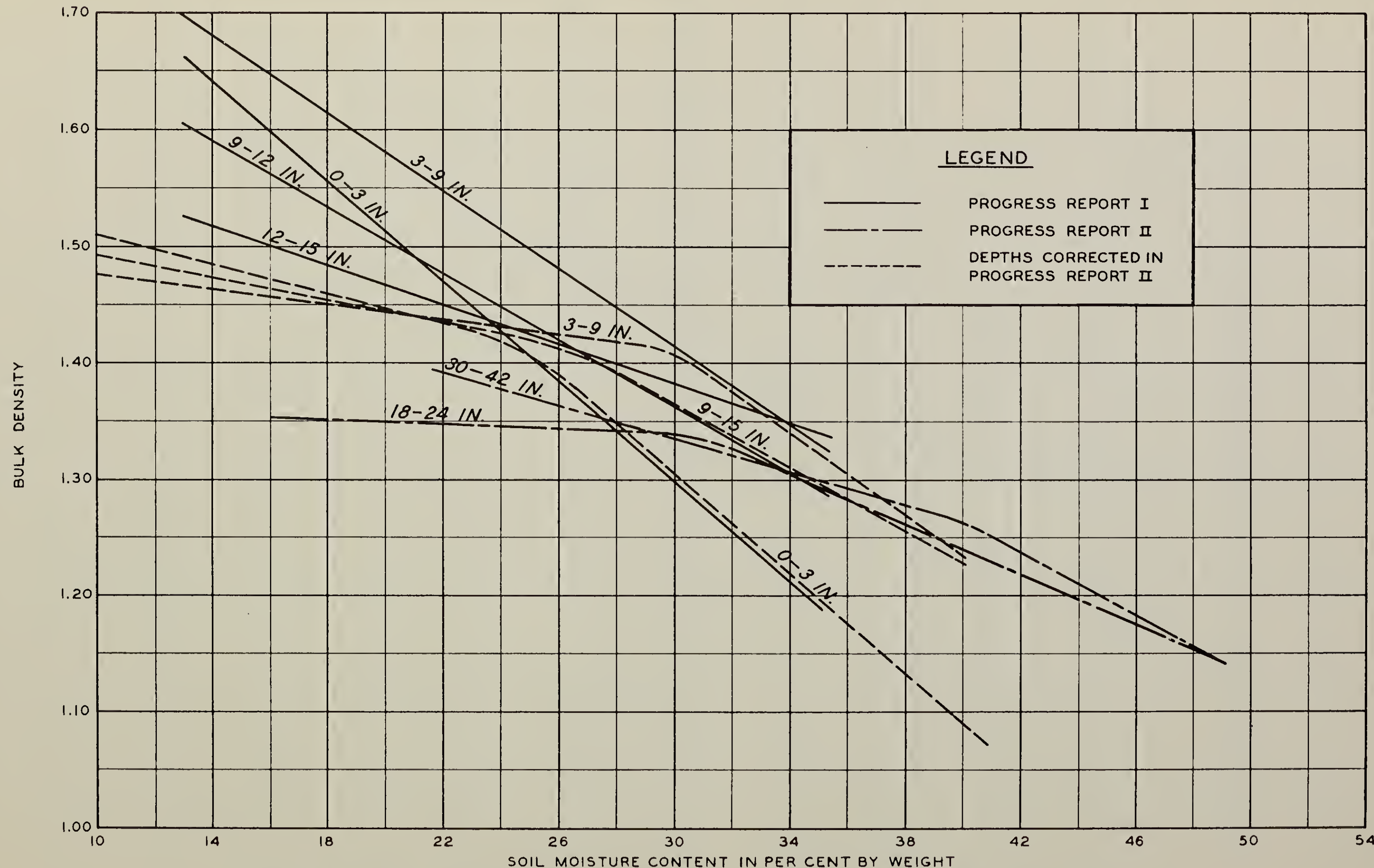

FIGURE 60. RELATION BETWEEN BULK DENSITY AND SOIL MOISTURE CONTENT

MOUND SITE

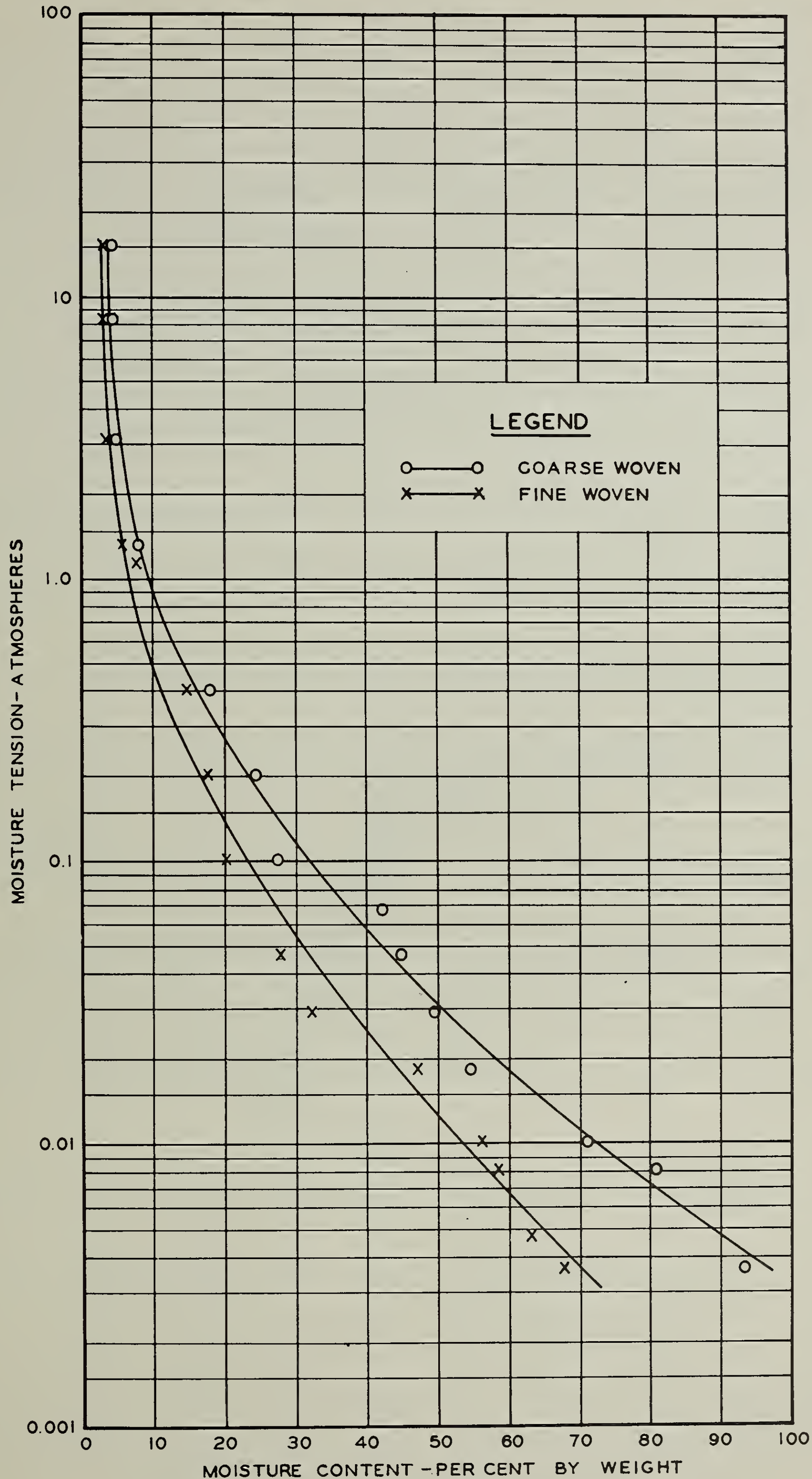

FIGURE 61. VARIATION OF MOISTURE CONTENT WITH MOISTURE TENSION IN FIBERGLASS

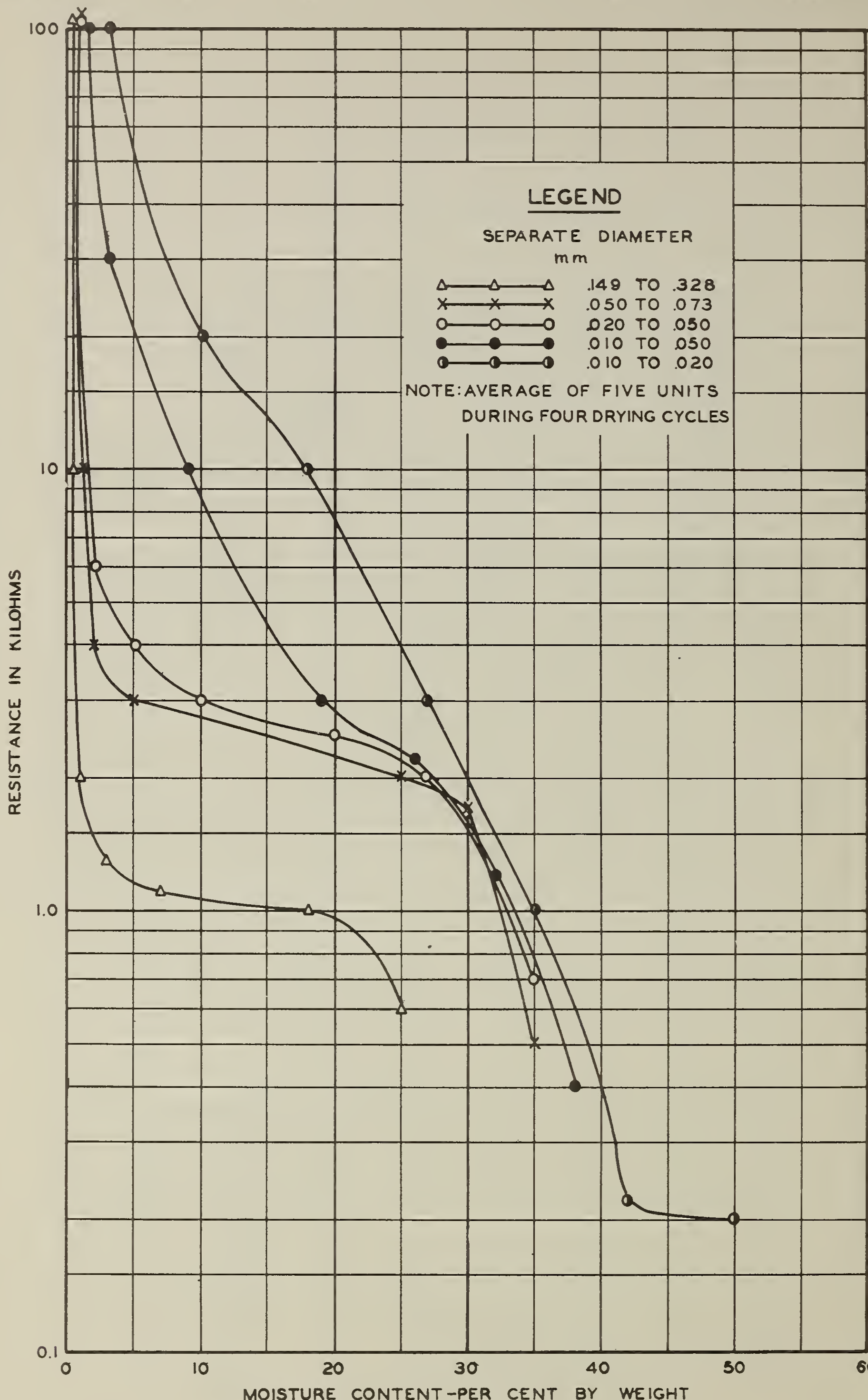

FIGURE 62. VARIATION IN RESISTANCE OF COLMAN UNITS WITH MOISTURE CONTENT IN SAND AND SILT SEPARATES

particle size decreases. The resistance does change in high moisture contents up to saturation of the separates, again indicating that these units do give a measure of high moisture contents. The moisture tension curves of the separates are shown in Figure 63. Comparing Figure 62 with Figure 63, the resistance-moisture content relation from the Colman units reflects the moisture-tension relationship of the separates throughout the range from saturation to the wilting point. The two curves are combined in Figure 64, showing the variation of resistance with tension. A change in resistance is shown at tensions less than field capacity.

Root Concentration and Moisture Depletion

Soil moisture depletion during summer conditions is determined largely by transpiration, water being absorbed by the plant roots. The depth of the absorbing roots determines the zone of moisture depletion. Results of root determinations in 3-in. layers at the sites were given in Progress Report I. For this study the per cent occupancy of roots was recalculated* and plotted against the average daily rate of moisture loss, Figure 65.

Considering that the depletion rates include evaporation as well as transpiration and that the former is active throughout at least the upper 6 in. of soil, these results show little relationship between rates of moisture loss and root concentration. The area of absorbing surface as well as root volume should be considered to better relate moisture depletion to root occupancy. The area can be determined from the additional

* Recent data (Table 26) indicate that fresh roots have a moisture content of 75 per cent and a specific gravity of 1.15.

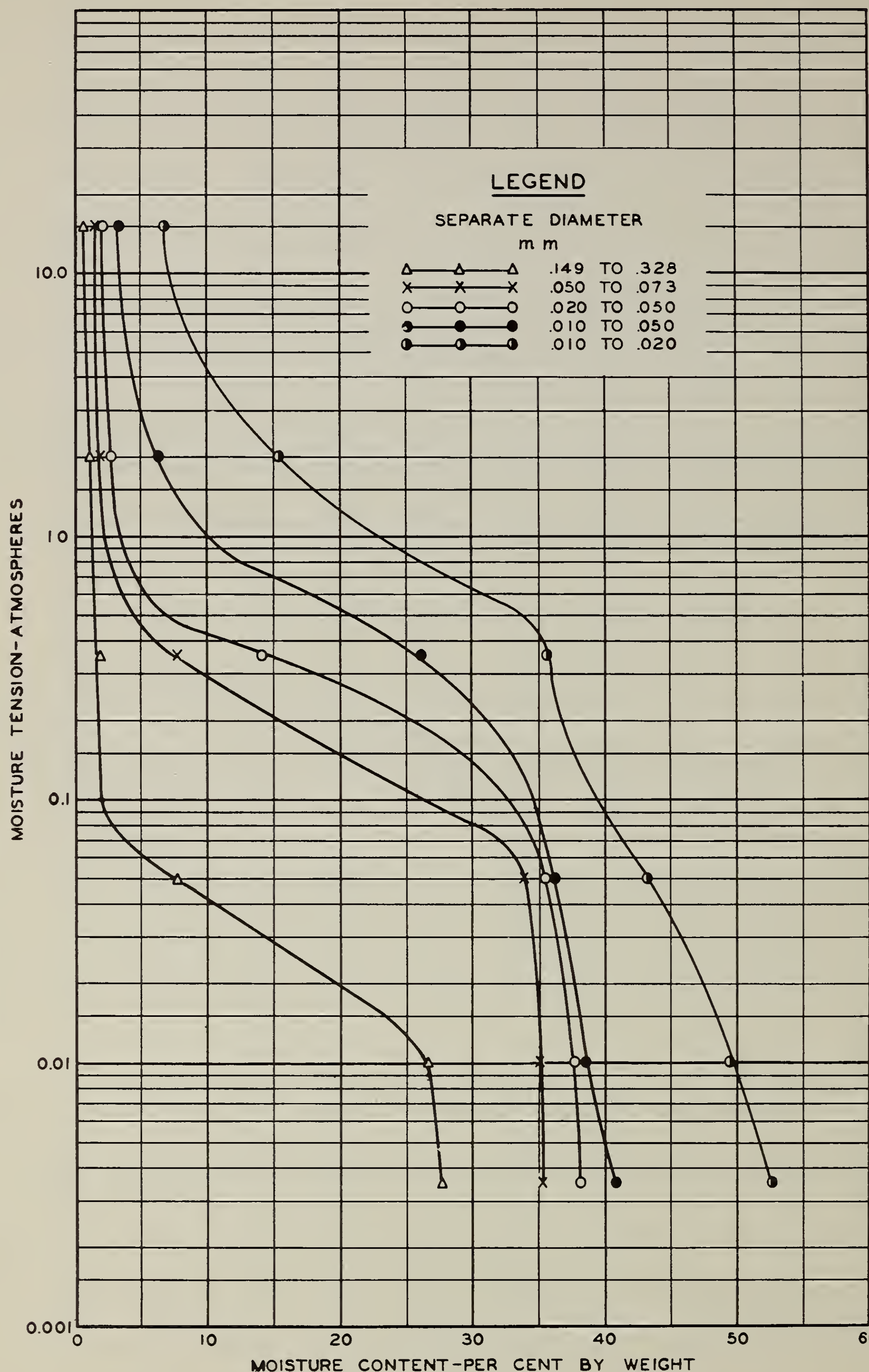

FIGURE 63. VARIATION OF MOISTURE CONTENT WITH MOISTURE TENSION IN SAND AND SILT SEPARATES

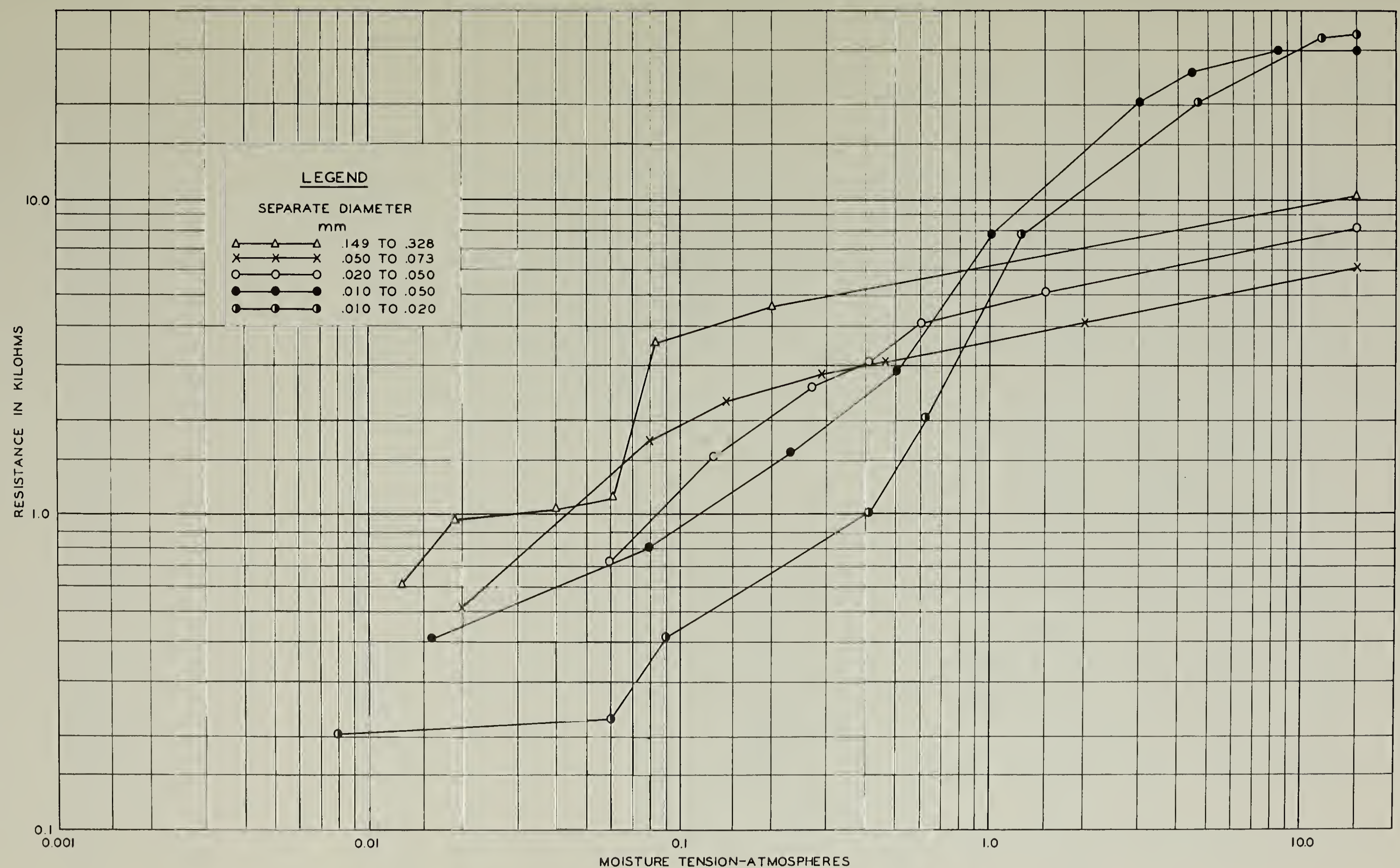

FIGURE 64. RELATION BETWEEN RESISTANCE OF COLMAN UNIT AND MOISTURE TENSION IN SAND AND SILT SEPARATES

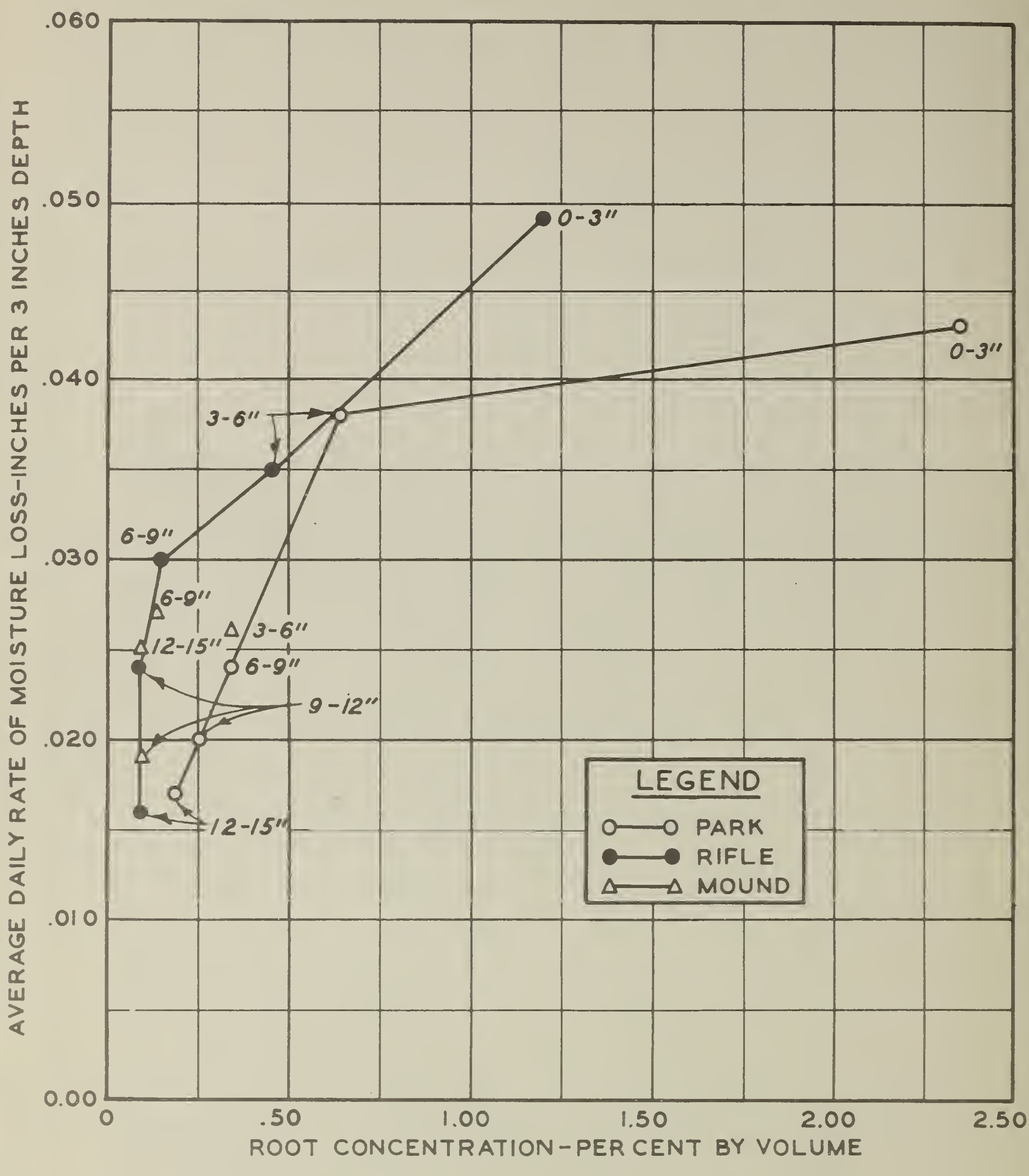

FIGURE 65. VARIATION OF DAILY RATE OF SOIL MOISTURE LOSS WITH ROOT CONCENTRATION

measurement of average root diameter.

A study was made to improve sampling, root separation techniques, and the expression of root concentration in volume, and area of absorbing surface. Samples were taken from the 3-6-in. depth at Rifle with the San Dimas core sampler. Three samples were suspended in a solution of 0.02N sodium hydroxide and 0.005N sodium oxalate and three others in tap water. The roots were collected on a 100-mesh sieve. Volume and density were determined using a wide-mouth picnometer. The average root diameters were determined from measurements with a microscope having a graduated eyepiece. The length and area of roots per volume of soil were calculated as well as the per cent occupancy by volume. The length and area are not necessarily proportional to per cent volume due to variations in root diameter.

Results, Table 26, show that the oxalate-hydroxide treatment does not affect the roots. The diameter, moisture content and density remain the same.

Table 26 is of some interest in indicating that despite relative small values of root concentration in per cent by volume or weight, the aggregate length and surface area per cubic volume of soil are considerable. For the six samples, the average aggregate length per cubic centimeter of soil was approximately 90 cm, the average surface area, 4 sq cm.

Evidence of considerable root occupancy was observed in soil fragments taken from the 24-in. depth at Rifle in January 1952. These fragments appeared riddled with tiny holes just visible to the naked eye. These holes ranged from 0.005 to 0.010 in. in diameter, values comparable to diameters measured in the above study. Figure 66, an enlarged photograph of the soil fragments, shows about 200 of these openings per square

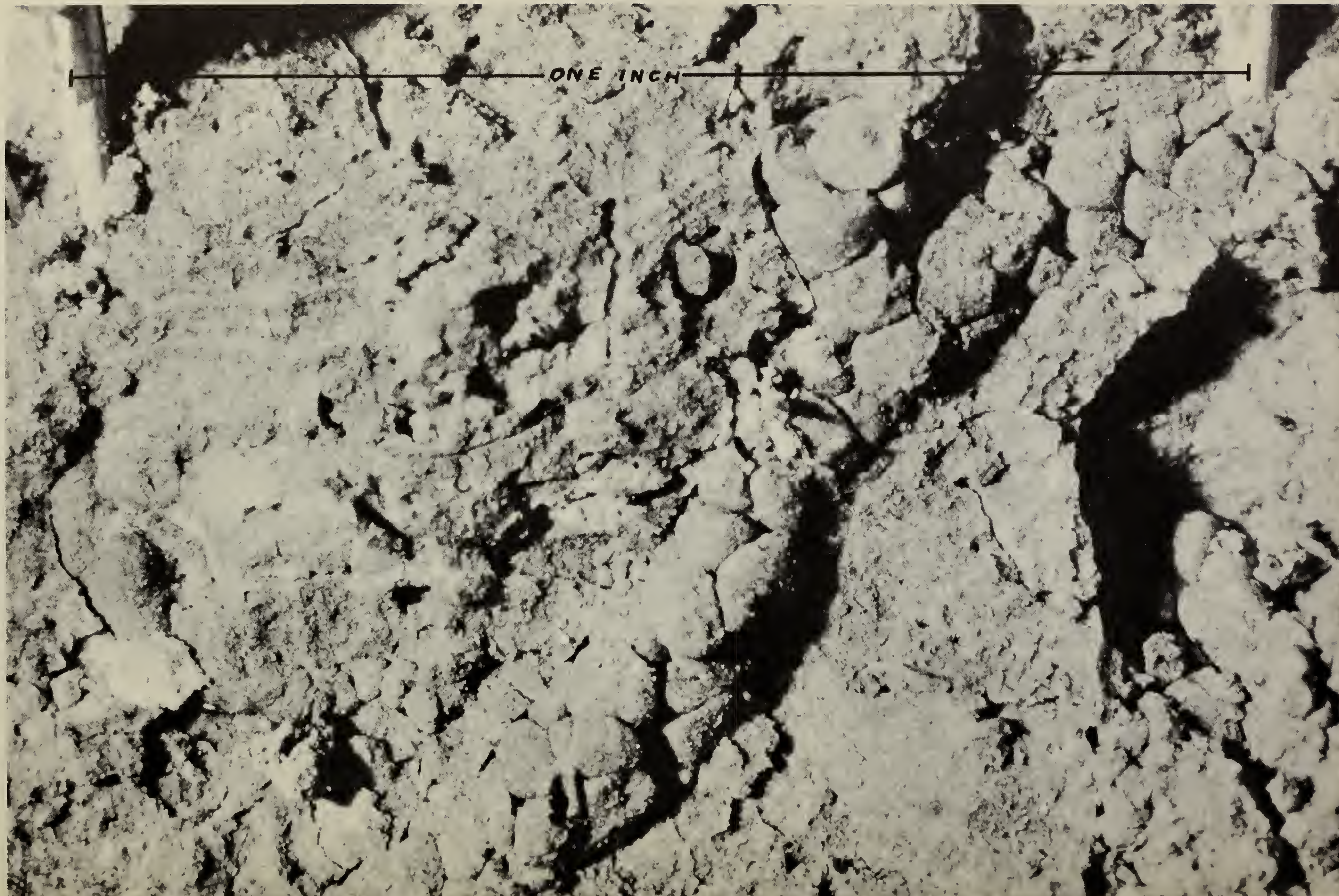

Figure 66. Enlarged fragment of Collins silt loam at 24-in. depth

Table 26

EFFECT OF METHOD OF DISPERSING SOIL SAMPLE ON ROOT CHARACTERISTICS AND ROOT CONCENTRATION

Rifle Site, 3-6-In. Depth

	Dispersion of Sample							
	Oxalate-Hydroxide				Tap Water			
	No. 1	No. 2	No. 3	Avg	No. 1	No. 2	No. 3	Avg
Root characteristics								
Average diameter fresh roots, cm	.0164	.0164	.0140		.0182	.0172	.0136	
Weight fresh roots, gm	5.816	5.225	5.421		7.721	4.466	4.619	
Weight dry roots, gm	1.402	1.341	1.543		1.947	.976	1.238	
Moisture contents roots, per cent (fresh weight basis)	75.9	74.3	71.5		74.8	78.2	73.2	
Density of fresh roots	1.134	1.132	1.157		1.167	1.130	1.157	
Density of dry roots (per volume of fresh roots)	.273	.291	.346		.294	.247	.310	
Soil characteristics								
Bulk density	1.362	1.369	1.411		1.366	1.376	1.407	
Root concentration								
Per cent volume of fresh roots (per volume of soil)	1.78	1.60	1.55	1.64	2.29	1.37	1.39	1.69
Per cent volume of fresh roots (per volume of available pore space 0-15 atm)	5.3	4.8	4.6		6.9	4.1	4.2	
Per cent weight of dry roots (per weight of oven-dry soil)	.36	.34	.38	.36	.50	.25	.31	.35
Aggregate length, m (per 100 cc of soil)	90.9	79.2	108.9	93.0	94.7	61.4	101.1	85.7
Aggregate area, sq cm (per 100 cc of soil)	434.	391.	442.	422.	505.	319.	408.	411.

inch or about 32 per sq cm. Considering that in the previous calculation there were about 90 cm of roots per cubic centimeter of soil, the face of the cube thus would also have approximately 30 openings.

FUTURE PLANS

Completion of Progress Report II marks the end of the first year's research program of the project. Research during the next year, April 1, 1952-April 1, 1953, will be directed principally toward securing a soil moisture and climatic record at prediction sites at Vicksburg and Laurel, Mississippi, and at Priest River, Idaho, and analyzing soil moisture and climatic data from other experiment stations. Specifically, the objectives are as follows:

a. At Vicksburg, to obtain a soil moisture record and develop prediction methods for the nontrafficable area at Durden, a hardwood and pine site, and bare areas at Rifle and Mound.

b. At Laurel, Mississippi, to conduct similar studies on herbaceous, hardwood and bare areas.

c. At Priest River, Idaho, to conduct similar studies on pine, herbaceous, burned, bog, and bare areas.

d. To obtain soil moisture and climatic data collected by the Forest Service in Pennsylvania, South Carolina, Utah, and California and to analyze them in respect to soil moisture predictions.

e. To correlate the prediction methods for the different climatic regions and vegetal and soil types.

f. To investigate the use of radioactive materials for measuring soil moisture and change of density with soil moisture.

g. To conduct any other special studies which will aid in the procurement and analysis of data for the derivation and application of prediction methods, or which will provide a fundamental basis for these methods through an understanding of the plant-soil-water relations involved.

h. To select suitable general areas and specific sites within these areas for location of work in the expanded program so as to provide representative coverage of soils and climatic conditions. To prepare specific work plans for the conduct of the expanded program.

i. To assemble sufficient infiltration and soil moisture measuring instruments to equip three field crews for the expanded program.

At the end of fiscal year 1953 the Forest Service will furnish to the Waterways Experiment Station a report, Progress Report III, covering the year's work. In addition, during this period the Forest Service will develop and maintain a staff of trained personnel for the expanded program.